Chapter 4 (ctd)
Fluid Dynamics

A brief Introduction

The motion of air around a wind turbine is a very complicated but interesting phenomenon. When several turbines are arranged into a wind-farm then the situation becomes even more complex. Fluid dynamics is the study of fluid (liquid and air) around one or a few objects, typically we consider air foils, cylinders and other bluff objects, and of course fish.

The motion of an element of fluid can be broken up into three parts (which can exit in combinations), this is shown in Fig.1 Translation is motion along a curve or streamline, when a fluid rotates it shows *vorticity* and fluid shear is caused by the fluid *viscosity* which is another word for friction. The actual behaviour of a fluid depends on its speed past an object, we expect streamlined flow without any vorticity for relatively small fluid speeds, whereas at higher speeds vortices are formed and at even higher speeds we experience a phenomenon called 'vortex shedding'. All of this will be explained below.

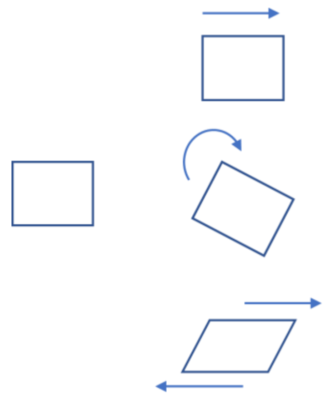


Figure 1 Types of fluid motion. The element on the left may translate (top), rotate (centre) and shear (bottom)

The maths of fluid dynamics is challenging, so we shall take a phenomenological approach here, gaining understanding from examples. One serious limitation is that our studies will be limited to 2D

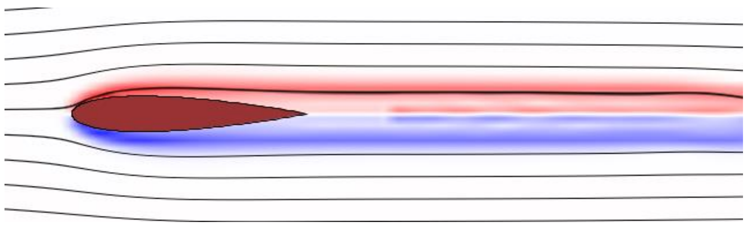
Flow past some simple shapes

Air Foil

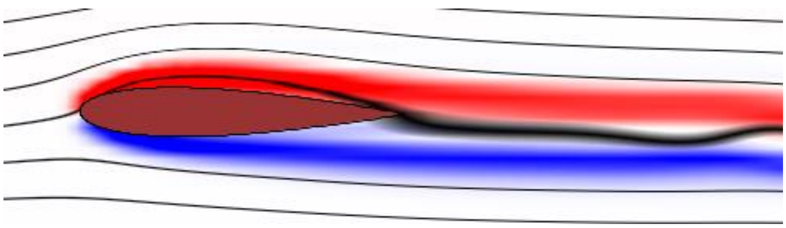
This shape is used for aircraft wings and wind turbines, there is actually a whole family of shapes, they are designed to have a large ratio of 'lift' force, (making the aircraft fly, or the turbine rotate), to the 'drag' force (opposing the aircraft motion or pushing against the turbine.

The flow of air around an airfoil at low speeds is shown in the diagram below (computed using ‘LilyPad’)

The flow is symmetrical, there is little circulation of air (vorticity). At a slightly higher speed the flow changes like this where the formation of vortices is clear.



How do airfoils produce lift? There are several ways to explain this, a simple one draws on Bernoulli’s principle, the faster the air, the lower its pressure. So when the wing is given a little angle of attack the speed over the top is more than under the bottom, so more pressure at the bottom, therefore lift. Another explanation draws on Newton’s laws. The example below shows the airfoil at an angle 0.5 degree

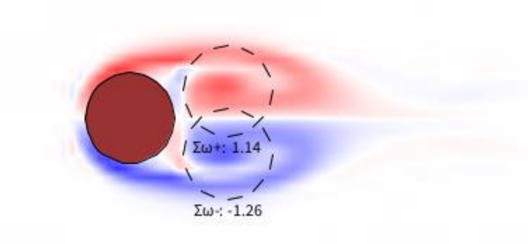


and the air leaving the airfoil has a clear downward component. The wing therefore experiences an upward lift force.

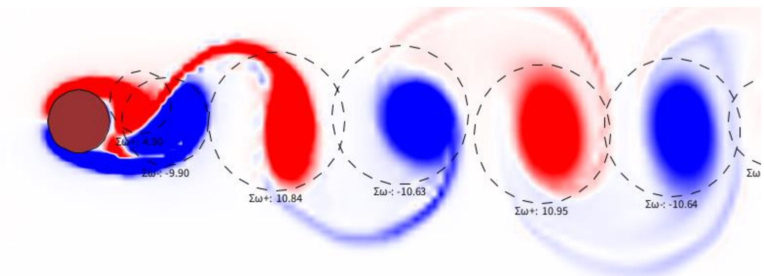
Cylinder

This is an important geometry which you find all around us, telephone and electricity cables, guy wires on bridges and antennas. At low fluid velocities there is streamlined flow around the object like this (speed 0.1)

and at higher velocities (0.5) we find strong vortices, which



rotate in opposite directions. At higher velocities these vortices detach from the cylinder, and form a Von-Karmen 'vortex street' behind the cylinder (v = 2.5)



This periodic shedding of vortices poses a problem in many situations. Since the vortices are alternately shed up then down, then they will apply a periodic force to the cylinder. This will excite it into oscillation. You may have heard telephone lines howling in the wind, it's this phenomenon you are experiencing. Vortex shedding destroyed the Tacoma Narrows Bridge and the Ferrybridge cooling tower.

At higher velocities turbulence results, it's not possible to visualize this with LilyPad.

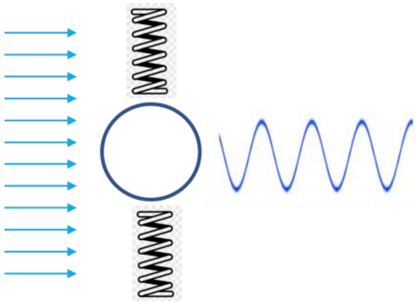


Figure 2 Structure of a Vibration Energy Harvester

Vibration Energy Harvesting (VEH)

Vortex shedding can be turned to use if the vibration is extracted from the cylinder. Usually, electricity is created using the piezo-electric effect, a material that produces electric charge when it is bent. The cylinder can be thought of as being suspended between two springs and will oscillate at the system's natural frequency, see Fig.2. Such bladeless turbines are being developed, while they may be around 25% as efficient as a conventional turbine, they may be built with a higher farm density. Current plans aim to produce power outputs of 4kW.

Much research is focused on development of microscale VEH and draw on a range of 'things that vibrate'. Replace your car shock absorbers with VEHs and charge your battery. But the biggest research interest at the moment is in VEHs which supply only milliWatts or microWatts of power. These could be used to power remote devices in the IoT age and also body-mounted monitoring devices. Yet interesting calculations appear in the literature. It is reported that about 85kW can be produced from a 70 storey building in the wind.