Introduction to Vortex Shedding

As we discussed in section (Dbc), the wake behind a cylinder in a uniform stream grows as the Reynolds number is increased above about $Re = 5$. Between $5 < Re < 50$ the steady attached vortices that form the wake behind the cylinder grow with Re. However about $Re = 50$ the width of the wake approaches the diameter of the cylinder and the wake becomes unstable in that it begins to oscillate back and forth behind the cylinder, veering from one side to the other. About $Re = 60$ this process leads to vortices breaking off and being convected downstream, with vortices alternately being shed from one side and then the other as illustrated in Figure 1. This phenomena occurs with a wide range of objects of many different sizes and

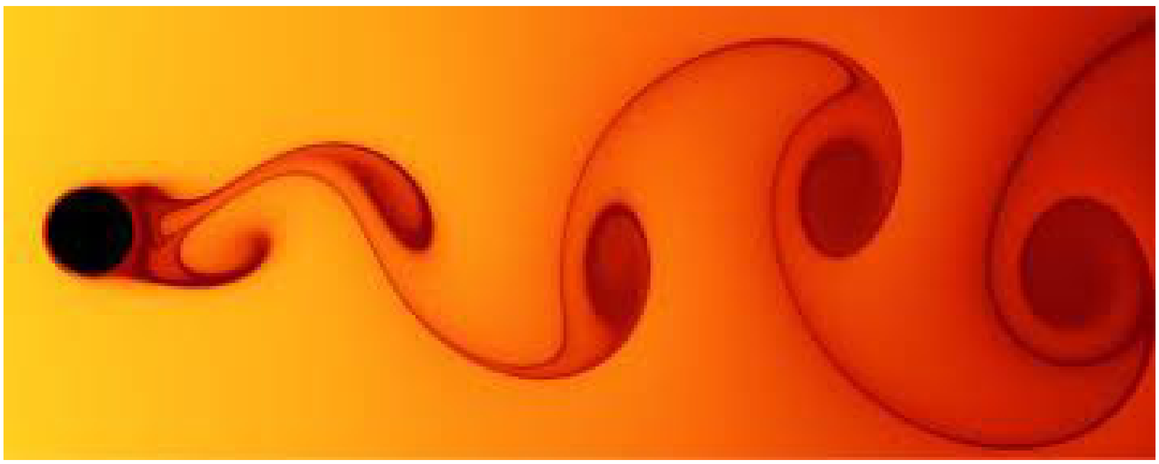

Figure 1: Karman vortex street behind a cylinder. Reproduced with permission of T.Colonius.

shapes. Figure 2 presents another example, the large cavitating vortices behind a cavitating hydrofoil.

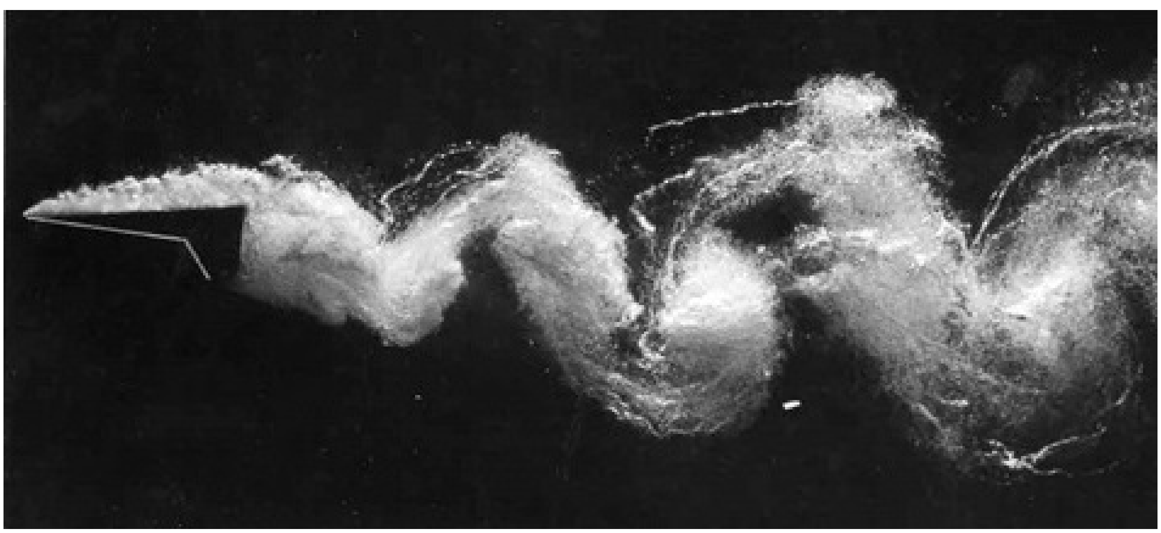

Figure 2: A cavitating vortex street behind a hydrofoil with a flap.

The pattern of alternate vortex shedding is known as a Karman vortex street and it continues as the Reynolds number increases from 60 to 5000 when a steadier laminar wake forms behind the cylinder.

However, vortices continue to be shed further downstream at the rear of the laminar wake as indicated by the flow visualized in Figure 3.

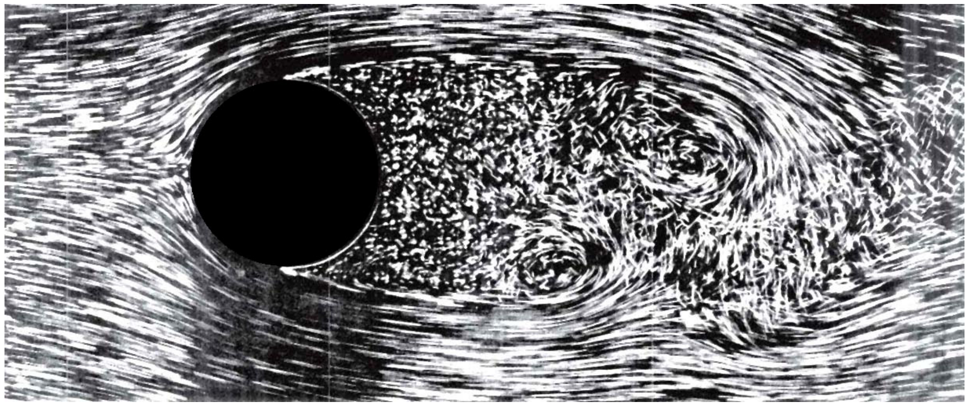

Figure 3: Formation of vortices in the wake of a circular cylinder.

The frequency of vortex shedding, f (Hz), is non-dimensionalized in the Strouhal number, $St = 2fR/U$, where U is the velocity of the impinging uniform stream and R is the radius of the cylinder. As illustrated by the data presented in Figure 4, experiments show that the measured Strouhal numbers remain remarkably constant at a value around 0.2 as the Reynolds number is increased from about 60 to 10^7 though the shedding begins to lose coherence around $Re = 10^5$ as turbulence invades the flow from the wake.

Because it occurs over such a wide range of Reynolds numbers (and object shapes), vortex shedding is a ubiquitous phenomenon. It occurs with scenarios as diverse as an oscillating violin string and large underwater structures (particularly when they are smooth or cylindrical). Figure 5 represents a particular meteorological example in which clouds in the atmosphere reflect the vortices shed by the island of Tristan de Cunha. Vortex shedding has also caused destruction of many man-made structures because the lateral forces generated during the shedding of each vortex can be very substantial. Early in the industrial revolution tall brick chimney stacks would sometimes sway and even break under the oscillatory lateral loads generated during vortex shedding. In modern times projections or ribs are often attached to large circular structures in order to fix the location of flow separation and thus stabilize the flow by minimizing the vortex shedding; Figure 6 shows a section of modern chimney with such fins attached. Also, in the early

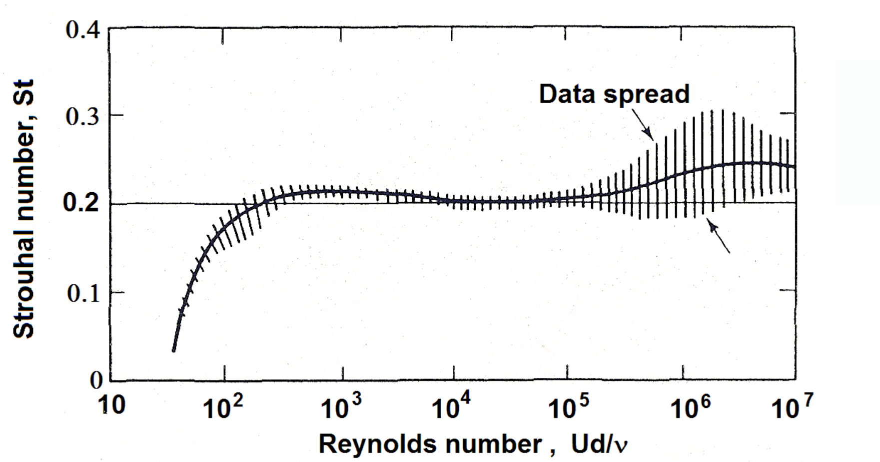

Figure 4: Measured Strouhal numbers for a circular cylinder as a function of Reynolds number. Adapted from Roshko (1954), Jones (1968) and White (1999).

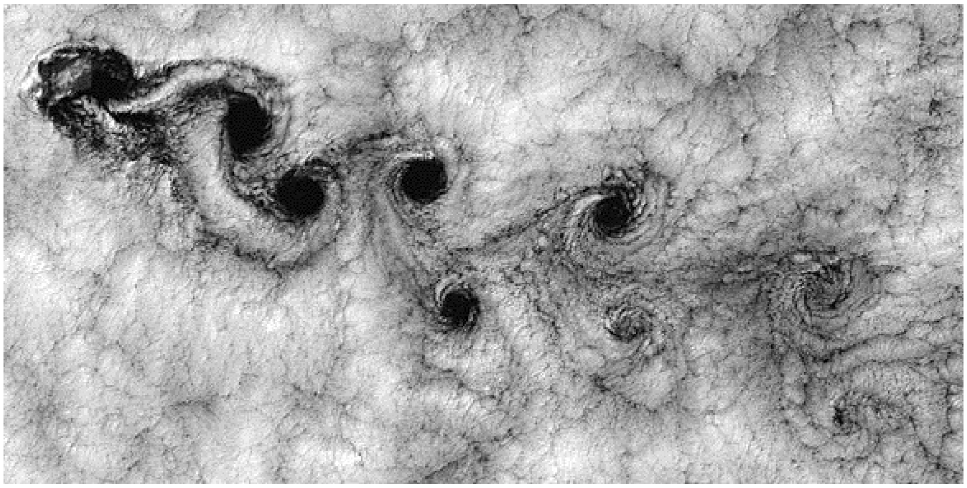

Figure 5: Karman vortex street reflected in the clouds above the island of Tristan de Cunha.

days of suspension bridges the vibration induced by vortex shedding sometimes caused the destruction of those bridges. Perhaps the most famous case, shown in Figure 7 was the self-destruction of the Tacoma Narrows suspension bridge.

Figure 6: Fins on large industrial chimney.

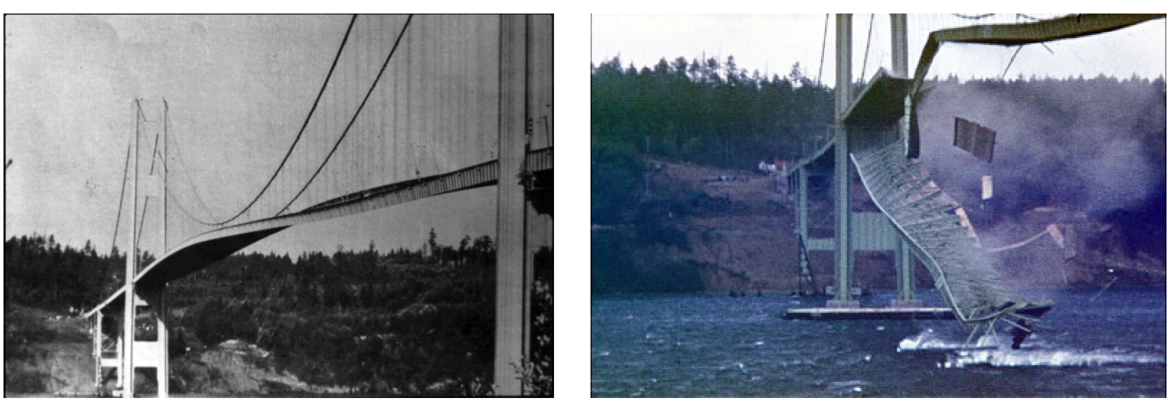

Figure 7: Failure of the Tacoma Narrows suspension bridge as a result of vortex shedding.