Avenue de Henri Benard

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When a flow happens around a solid body, at certain speeds, the flow downstream of the body separates into a time periodic alternating ejections of vortices. This is known as the Karman vortex street, named after Theodore von Karman, a first generation disciple of Ludwig Prandtl, who first proposed the concept of a viscous boundary layer with which one can explain this phenomenon. If the body is of circular cross section, the vortices eject from the top and bottom portion of the circular cross section. This is a beautiful phenomenon to observe even in a small size laboratory experiment. Here is a picture in a laboratory scale [1].

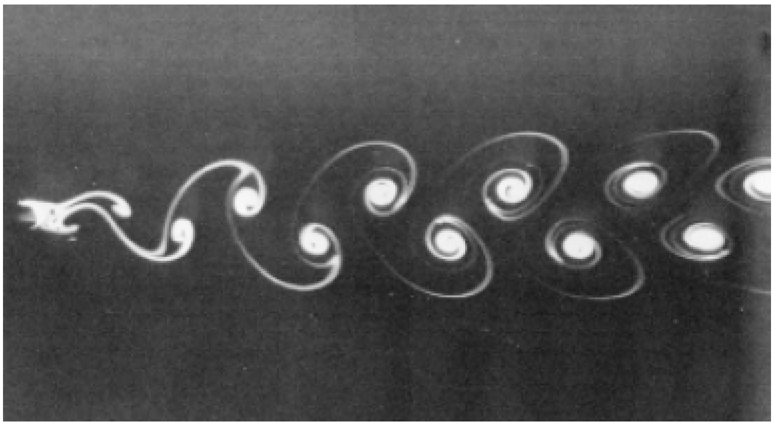
Like other such phenomenon, Karman vortices abound in Nature. Here is one recent instance pictured by NASA satellite where a karman vortex street is formed by the 'flow' of clouds over the island of Jan Mayen on Greenland.

The parallel dark and light streaks are cloud streets (not Karman vortices) formed by cold winds meeting moist air above the ground. The Jan Mayen island (my guess from the scale of the picture, should be about 20 km across) influences the local weather by posing as an obstacle for the wind. In turn the cloud street above and downstream (downwind) of the island is split into a continuous stream of alternating vortices.

More details of the vortices can be observed in the larger size image available at the NASA site [2].

A brief (and crude) technical summary of the Karman vortex trail: With respect to the laboratory scale picture above, consider a small fluid region upstream of the obstacle (cylinder). As it approaches the leading edge (front end) of the cylinder, the pressure increases to stagnation pressure as the flow is

[1] intended as course notes.



Karman vortex street behind a cylinder placed in uniform flow. Re ~ 300 [Courtesy: Sadotoshi Taneda; from An Album of Fluid Motion by Van Dyke (1982)]

Fig. 1. von Karman Vortex Street. Picture Credit: Ref. [1]

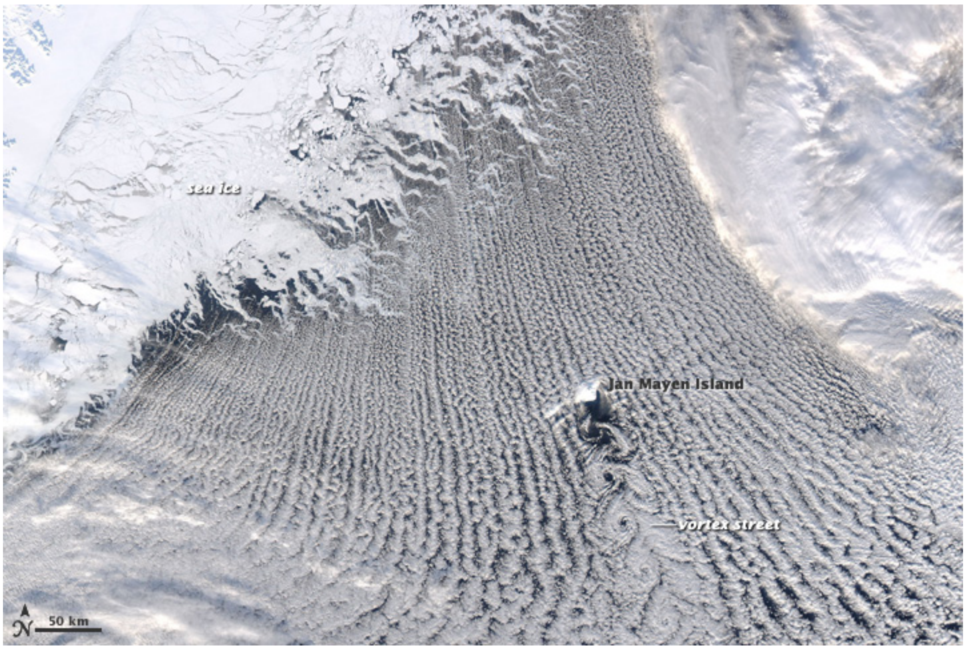


Fig. 2. Cloud Vortex Street around Jan Mayen Island on Greenland. Picture Credit: NASA (Ref. 2)

deccelerated. The region of fluid bends and goes around the cylinder on both sides (top and bottom). But there is a free stream flow that persists above and below the cylinder. So our fluid region squeezes around and near the cylinder surface. However, beyond certain higher flow rate, the high pressure caused in the front end is not sufficient to hold the two fluid streams around the cylinder surface. They separate from the cylinder just around the corner. This is called boundary layer separation. The separated layers form two fluid shear layers towards the downstream. The region farther from the cylinder surface moves with a higher velocity since it is in contact with the free stream flow. By contrast, the shear layer region near the cylinder surface in with a lesser velocity. The resulting shear causes the shear layer itself to tumble and roll downstream. Obviously the top vortex spins clockwise while the bottom vortex spins anti clockwise. The alternating ejection of such vortices downstream of the cylinder results in the Karman vortex street.

The frequency of shedding of these vortices can be calculated for simple obstacles by relating what is known as the Strouhal number with the Reynolds number of the flow. In general, for a given cylinder diameter, the frequency of shedding increases with increase in the Reynolds number (i.e. for increasing flow speed around the obstacle). Viscous fluid flow texts [3] would explain further details.

There is an interesting anecdote involving Henri Benard on these vortices getting named as Karman vortices. Henri Benard, a gifted experimenter with foresight, among other things, was the person credited with the first laboratory scale experiment observing, what is known today as the Rayleigh-Benard convection [4]. In another of his experiments, he did observe much before von Karman, what is credited as Karman vortices. Let me quote von Karman himself on this, from his book [5]:

> The arrangement of the vortices [...] is connected with my name; it is usually called a Karman vortex street or a karman vortex trail. But I do not claim to have discovered these vortices; they were known long before I was born. The earliest picture in which I have seen them is one in a church in Bologna, Italy, where St. Christopher is shown carrying the child Jesus across a flowing stream. Behind the saint's naked foot the painter indicated alternating vortices. Alternating vortices behind obstacles were observed and photographed by an English scientist, Henry Reginald Arnulpht Mallock (1851 - 1933) and then by a French professor, Henri Benard (1874 - 1939). Benard did a great deal of work on the problem before I did, but he chiefly observed the vortices in very viscous fluids or in colloidal solutions and considered them more from the point of view of experimental physics than aerodynamics. Nevertheless, he was somewhat jealous because the vortex system was connected with my name, and several times - for example, at the International Congress for Applied Mechanics held in Zurich (1926) and in Stockholm (1930) - claimed priority for earlier observation of the phenomenon. In reply I once said, 'I agree that what in Berlin and London is called 'Karman Street' in Paris shall be called 'Avenue de Henri Benard.' After this wisecrack we made peace and became quite good friends.

So what exactly von Karman contributed to the understanding of this phenomenon? He proved analytically that a symmetric configuration of vortices (two streams of equidistant but oppositely spinning vortices, one above the

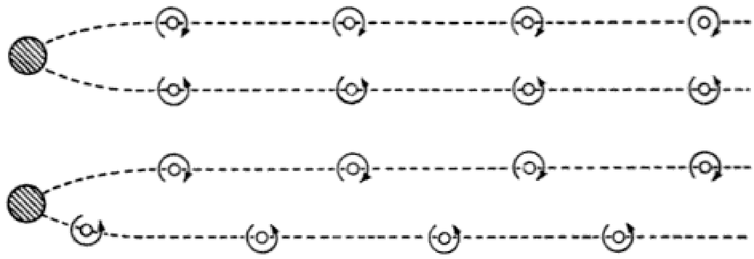


Fig. 32. Double rows of alternating vortices; symmetric (*upper*) and asymmetric (*lower*) arrangements.

Picture Credit: Aerodynamics by T. von Karman, McGraw Hill Pub. 1954 [Ref. 5]

Fig. 3. Stability of Karman vortex street configuration. Picture Credit: Ref. [5]

other) downstream of an obstacle is an unstable configuration. He also showed that the stable configuration is the alternating pattern of oppositely spinning vortices that we observe in the pictures. The stability of the configuration depends on the ratio of the distance between the two rows and the distance between two consecutive vortices of each row.

Such Karman vortices happen only in a narrow window of flow rates around a solid body of particular cross section size. For lower flow rates, the flow coats the body almost symmetric up and downstream. There is no instability. For much higher flow rates the flow separates from the body. Karman vortex trail is one of the phenomenon observed in a continuous movie of laminar to turbulent flow phenomena around an obstacle. Turbulence in Flow around Bodies note contain more details.

The phenomenon of Karman vortices can be associated with other natural phenomenon such as the Aeolian tunes or the singing of the trees and even telegraph wires (which is what Strouhal investigated). Such vortex shedding also adversely affects tall columns kept in fluid flow - such as the foundation pillars of off shore oil rigs and automobile antennas. To explain such things even briefly, it would take another note - for which, let this one serve as an introduction.

To close, here is another picture of Von Karman vortices in ocean water off Rishiri Island, Japan. The picture is taken again by one of the satellites of NASA.

And for an encore, here is a picture of the Karman vortex street in the Pacific Ocean taken on Aug 1, 1973, by the one that fell on our heads on a later date.

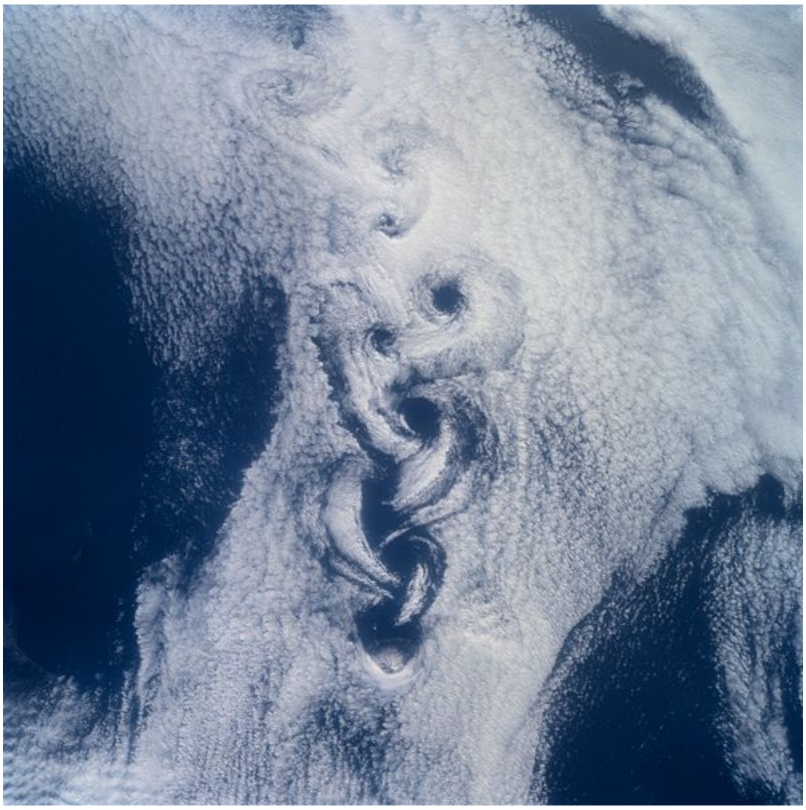


Fig. 4. Karman Vortex Street off Rishiri Island, Japan. Picture Credit: Ref. [6]

Fig. 5. Karman Vortex Street in the Pacific, taken by SkyLab. Pic. Credit: NASA

References

(1) Picture from An Album of Fluid Motion by Milton Van Dyke

(2) NASA Earth Observatory - Image of the day
(3) Viscous Fluid Flow, F. White, Wiley Pub.
(4) See the note Rayleigh Benard Convection at `http://www.nonoscience.info/`
(5) Aerodynamics by Theodore von Karman, 1954, McGraw Hill Pub. (original print: Cornell Uty. Press)
(6) Wikipedia Link
(7) Theodore von Karman - biographical note