# NOTES AND CORRESPONDENCE

## GLOBAL FLOW-VISUALIZATION
## OR
## "THEODORE VON KÁRMÁN WINS AGAIN!"

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In 1911–12, the brilliant scientist–experimentalist–analyst Theodore von Kármán (1881–1963) developed his now-famous theory of the "vortex street" (Goldstein, 1938; Schlichting, 1968) in which a circularly cylindrical body, when exposed to a fluid flowing perpendicular to its length, alternately sheds vortices from opposite sides of it. This phenomenon is familiar to many of us as the cause of the "humming" of telephone or power lines in high winds, a sound which is usually referred to as "Aeolian tones." It is extremely important in that it can have very destructive effects on stacks and chimneys and the like and also, to a lesser extent, on suspended cables.

Since von Kármán's original work, considerable research has been conducted into the theoretical and experimental aspects of vortex shedding from cylinders (e.g. Roshko, 1954a, 1954b, and 1961; Schlichting, 1968; Wooton and Scruton, 1971). Although the phenomenon is still not perfectly understood, many interesting results have been obtained. For example, it was originally thought that organized vortex shedding occurs over only a very limited range of Reynolds number ($Re \equiv \rho VD/\mu$; see Fig. 2 for definition of symbols). Laboratory results have shown, however, that it exists to a Reynolds number of at least $10^7$ (Roshko, 1961), and there is no reason to believe that this value is an upper limit. It is virtually impossible to produce higher values of $Re$ in the laboratory, however, so results in this range have remained largely unavailable. Another result has been the determination of the frequency with which the vortices are shed from the body. This frequency is usually expressed in terms of a Strouhal number, which is defined by $St = fD/V$. The Strouhal shedding frequency appears to be about 0.27 for circular cylinders at high $Re$, decreasing to about 0.20 for lower values of $Re$ and 0.10–0.25 for non-circular cross-sections.

The purpose of this brief note is to focus attention on the photograph of Fig. 1 in light of von Kármán's original two-dimensional vortex shedding theory and some of the more recently observed aspects of the phenomenon. The photograph displays a splendid example of the natural occurrence of a form of vortex shedding on a Reynolds number scale ($Re \sim 10^{10}$) far greater than

Fig. 1 Photograph of the flow of air past Isla de Guadalupe (Mex.) off the coast of Baja California, obtained at the Atmospheric Environment Service on 25 Aug. 1976 (NOAA 5, Orbit #334). Mist and clouds provide the medium needed to make the flow structure visible.

can be achieved in typical laboratory experiments. It was obtained in the Atmospheric Environment Service Satellite Data Laboratory and shows the flow of air past Isla de Guadalupe off the coast of Baja California. While such photographs have become fairly familiar in recent years (e.g. Bayliss, 1976), they remain a pleasing reminder of the existence of the phenomenon on a global scale and of the flow-visualization capabilities that are provided by satellite photography.

We can examine some of the relevant parameters of the present flow by using dimensional information from the photograph and wind data from the island for this date. The flow is reconstructed in Fig. 2 and appropriate values are given. Using these data, we obtain a Reynolds number of $5.2 \times 10^9$ and a Strouhal number of 0.15. The latter value certainly agrees favourably with

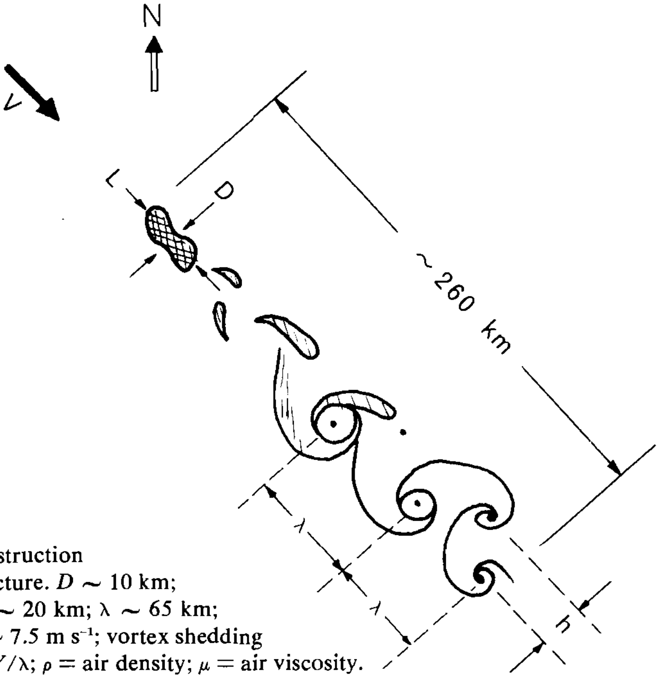

Fig. 2 Reconstruction of the flow structure. $D \sim 10$ km; $L \sim 35$ km; $h \sim 20$ km; $\lambda \sim 65$ km; wind speed $V \sim 7.5$ m s$^{-1}$; vortex shedding frequency $f = V/\lambda$; $\rho$ = air density; $\mu$ = air viscosity.

those quoted above, especially when it is kept in mind that this full-scale case represents a three-dimensional flow over a mountain that is 1300 m high, as opposed to a controlled two-dimensional flow past a cylinder!

Finally, it is interesting to calculate the value of $h/\lambda$ for this flow (see Fig. 2). In his original theory, von Kármán concluded that the vortex street would remain stable only if this ratio were equal to 0.28. From the photograph, we obtain a value of $h/\lambda \sim 0.3$!

You win again, Dr von Kármán!

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