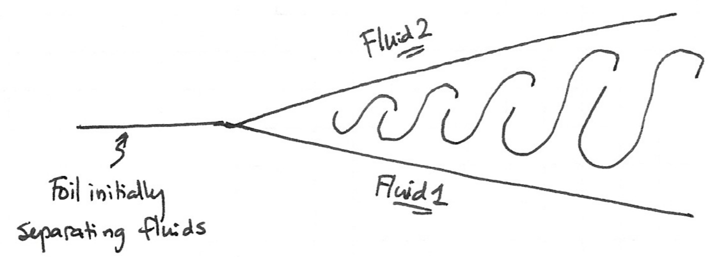
Structure in Turbulence:

Big whorls have little whorls,
which feed on their velocity;
and little whorls have smaller whorls,
and so on to viscosity (in the molecular sense).
– Lewis Fry Richardson, 1922

The idea that the apparently random velocity fields associated with turbulence could have quantifiable structure is relatively new. In their 1974 experiments, Brown and Roshko observed large-scale, largely two-dimensional structures in high Reynolds number mixing layers. An image from their experiment is included on the D2L website, and it looks roughly as follows:



The large structures seen in the above cartoon are referred to as mixing layer rollers, and the gaps between adjacent rolls are referred to as braid regions. In their 1967 experiments, Kline et al. made the first observations of near-wall low-speed streaks. In these streaks, the instantaneous velocity is less than the local average velocity. These streaks are intermittent in space and time but appear on average at a regular transverse spacing. It is now known that these streaks result from the presence of streamwise vortices which convect low momentum fluid away from the surface of the wall. Since the aforementioned discoveries, there has been a great deal of research investigating the structure of turbulence.

For the concept of structure in turbulence to make sense, the structures must be generic properties of the turbulence. The character of the structures must be the same no matter where you look. The idea that a turbulent flow field might have predictable structural features is consistent with the concept of a "turbulent attractor", and these features may be captured using higher-order statistics such as the two-point correlation.

The appeal of turbulent structures in the study of turbulence is that if one knows what the structures are, one may be able to determine how they will evolve based on simple fluid-dynamic considerations such as the Biot-Savart law. Notably, the velocity field admits the solution:

$$\vec{u}(\vec{x},t) = -\frac{1}{4\pi}\int \frac{\nabla\times\vec{\omega}(\vec{x}')}{|\vec{x}-\vec{x}'|}\,d\vec{x}' \qquad \text{(Biot-Savart Law)}$$

When the vorticity is concentrated in filaments, then the integral above only has support on the filaments, and to evolve the filaments we need only evaluate the integral on the filaments. Thus, in principle, we can understand the evolution of concentrated vortices using the Biot-Savart Law. This has been the reason much of the focus of turbulence research on small-scale structures has been directed at identifying vortices.

Throughout the rest of the class, we will often discuss the presence and impact of structures. For more information, refer to Chapter 5 of "Statistical Theory & Modeling of Turbulent Flows" by Durbin and Reif.