Streamlines, Pathlines and Streaklines

The ability to visualize a flow, either experimentally, analytically, computationally or conceptually, is an important step in understanding that flow and its consequences. In this section we consider how the motions in a flow can be visualized and the terminology used in interpreting those observations. While we could consider visualizing other properties of a flow such as the pressure, temperature, salinity, etc., the most widely used methodolgies involve visualizations of the fluid motions and velocities and we shall focus on these methods here.

We begin by defining the various lines in a flow which the particles of fluid can trace out as the flow proceeds. Three of these, the most common, are called streamlines, pathlines and streaklines. After defining each of these it is useful to illustrate them by analogy with the flow of vehicles on a busy highway. It is also valuable to discuss the specifics of the common experimental methods used to visualize each of these three types of flow line.

A *streamline* is a line in a flow that is everywhere tangent to the velocity vector at the particular instant in time at which the observation is made. Consequently, for every moment in time, we could visualize constructing any number of lines that would fill the whole field of flow being examined. However, in general, those lines would change with time.

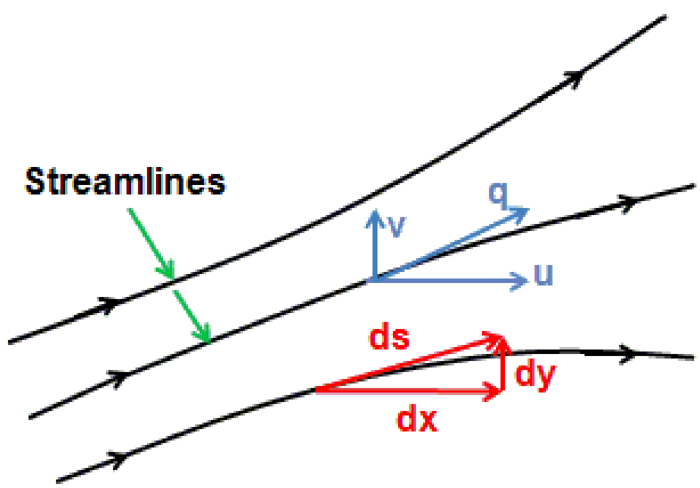

Figure 1: Streamline properties.

One way to visualize streamlines experimentally would be to fill the fluid with tiny but visible particles that will follow the fluid motion and then to take a photograph of that flow using an exposure time that is short but just long enough that each particle shows up as a short line. Then one could construct within that image streamlines that are everywhere tangent to those short particle-traced lines. One could imagine doing this with a night photograph of a highway using an exposure of, say, $1/25th$ second so that the vehicle tail-lights create short red lines in the photograph (see Figure 2). In this instance it is clear that the "streamline" (blue dashed line) joining these red dashes would correspond to the highways. In wind tunnel or water tunnel experiments one is often primarily concerned with the flow over the surface of an object such as a model automobile. A technique often employed in these circumstances is to attach small lengths of thread at a whole array of points on the surface of the object. Then, the threads stretch out in the local direction of flow and one can visualize the flow by conceptually constructing lines that are everywhere tangent to the stretched threads. Frequently such experiments focus on regions where the flow reverses or "separates" and these can often be detected by such methods. Other similar experimental techniques involve paint or oil drops placed on the surface to "run" in the direction of the flow.

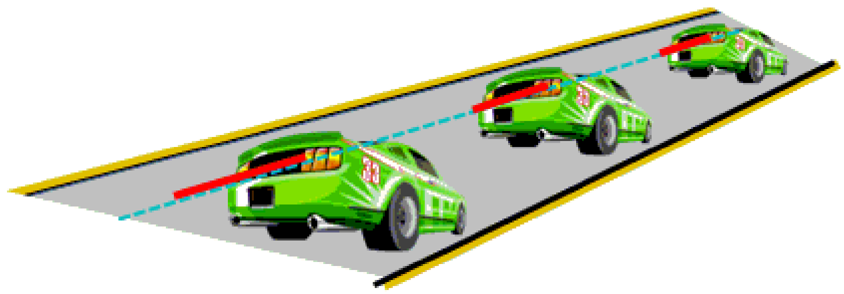

Figure 2: Streamline (blue dashed line) from short time exposure involving multiple cars.

A *pathline* is a line in a flow that is traced out by a particular particle. In the particle-seeded fluid flow described above we can visualize fixing attention on one particular particle and recording the path that it took within the flow. This pathline therefore is recorded over the period of time for which the fluid particle is visible. If the flow was unsteady then another particle, released at the same starting point, would not necessarily follow the same pathline. However, if the flow is steady this second pathline would be precisely the same as the first. Furthermore, by extension it follows that, in a steady flow, the pathlines and streamlines coincide.

It is conceptually simple to envision recording pathlines in a flow. One would simply release a tiny but visible particle that will follow the fluid motion and then take a long exposure photograph of that flow that would show the pathline traced out by that particle. One should use a tiny particle because that will exhibit less motion relative to the fluid and therefore follow the fluid motion more closely. Often one sees long exposure photographs of highways at night which show the pathlines traced out by the rear lights of vehicles (see Figure 3).

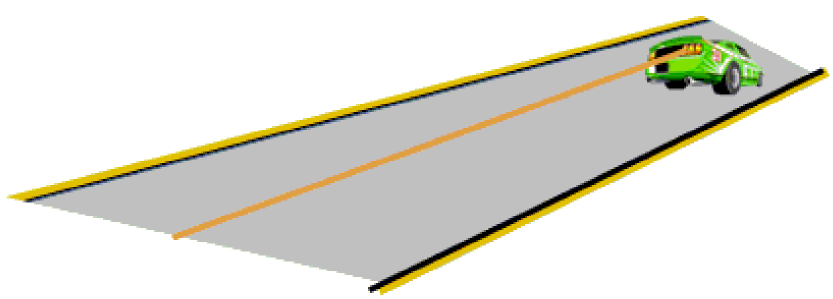

Figure 3: Pathline from long time exposure involving single car.

A *streakline* is a snapshot at one instant in time of all the particles which passed through a particular Eulerian point in the fluid. For example one could imagine injecting a regular stream of bubbles into a liquid flow and then taking a short exposure photograph of that line of bubbles at some particular point in time. The bubbles would visualize the streakline for the Eulerian point at which they were injected. If the flow is steady these streaklines would coincide with the streamline passing through the same Eulerian point. However, in an unsteady flow the two may be different.

Experimentally, streaklines are relatively easy to record. One can release a stream of dye or a succession of small bubbles and then take a short exposure photograph in order to record the streakline, perhaps for a whole succession of moments in time. One can also record streaklines for an array or points by injecting dye or bubbles through a whole line of injection points in the flow. One technique often used in water flows is to set up a voltage difference between a wire stretched across the flow and the metal of the containing vessel and thus produce bubbles all along the wire by electrolysis.

On a highway one could imagine identifying all the vehicles that entered the highway via a particular entrance ramp (see Figure 4). Then the line defined by that succession of vehicles would be a streakline.

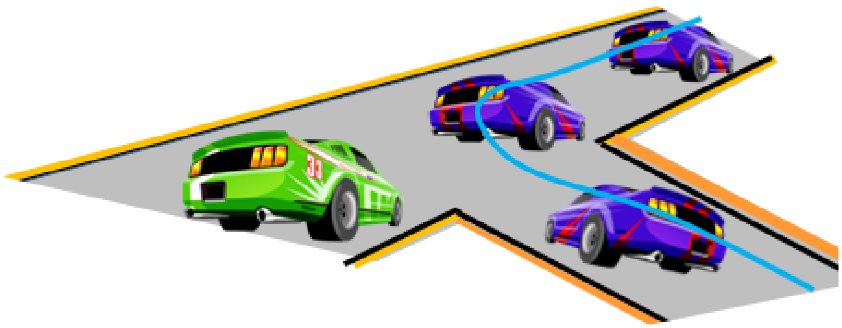

Figure 4: Streakline (blue) connecting all cars passing through a particular point.

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We now focus again on streamlines in order to present some of the properties of streamlines in more detail:

- **Streamline velocity relations.** Since streamlines are everywhere tangential to the fluid velocity vector as shown in figure 1 it must follow that over an infinitesmal interval of time, dt, a particle of fluid would be displaced by increments dx, dy, dz, in the x, y and z directions where

$$dx = u\ dt \quad ; \quad dy = v\ dt \quad ; \quad dz = w\ dt \qquad \text{(Bcg1)}$$

so that the slope of the streamline is given by

$$dx/u \ = \ dy/v \ = \ dz/w \quad ; \quad \frac{dy}{dx} = \frac{v}{u} \qquad \text{(Bcg2)}$$

We use these relations when defining the stream function in a following section.

- **Streamlines and boundaries.** Since fluid cannot pass through a solid wall or boundary it follows that the velocity vector at that wall must be tangential to that boundary and therefore that some streamlines must be coincident with that wall boundary. Conversely in a planar flow for example, the wall must be a streamline.

- **Crossing Streamlines.** Since streamlines are everywhere tangential to the fluid velocity vector, at a point of intersection of two streamlines the fluid velocity must be zero since a non-zero velocity vector cannot have two different directions at that intersection point. Such a point in a flow is called a **Stagnation Point**.