Streamlines, Particle paths, and Streaklines

By Scott Imlay, PhD
Director of Research, Tecplot, Inc.

Much like leaves in a breeze, streamlines, streaklines, and particle paths provide a useful visualization of complex vector fields. They yield detailed information about the vector direction and magnitude in user-selected localized regions without the clutter associated with many other vector field visualization methods.

Streamlines are lines that are everywhere parallel to the instantaneous vector field at the desired time, t_0. These lines are computed by integrating the ordinary differential equations below in pseudo-time τ.

$$\frac{d}{d\tau}\vec{x}(\tau) = \vec{v}(\vec{x}(\tau), t_0)$$

You are probably familiar with the concept of a streamline if you have used Tecplot 360, which refers to them as streamtraces. Suppose that the vector field represents the velocity of a fluid. For steady flows (vector field not changing with time), streamlines are the path an imaginary massless particle would take if it were released into the flow.

For vector fields that do not vary over time, streamlines, streaklines, and massless particle paths are exactly the same thing. The distinction only exists for unsteady (time-varying) vector fields.

Particle paths are lines tracing the path of a massless particle (think of a leaf) over time as it moves in the direction and speed dictated by the vector field. These lines are computed by integrating a similar ordinary differential equation through real time, t, using the actual time-varying values of velocity.

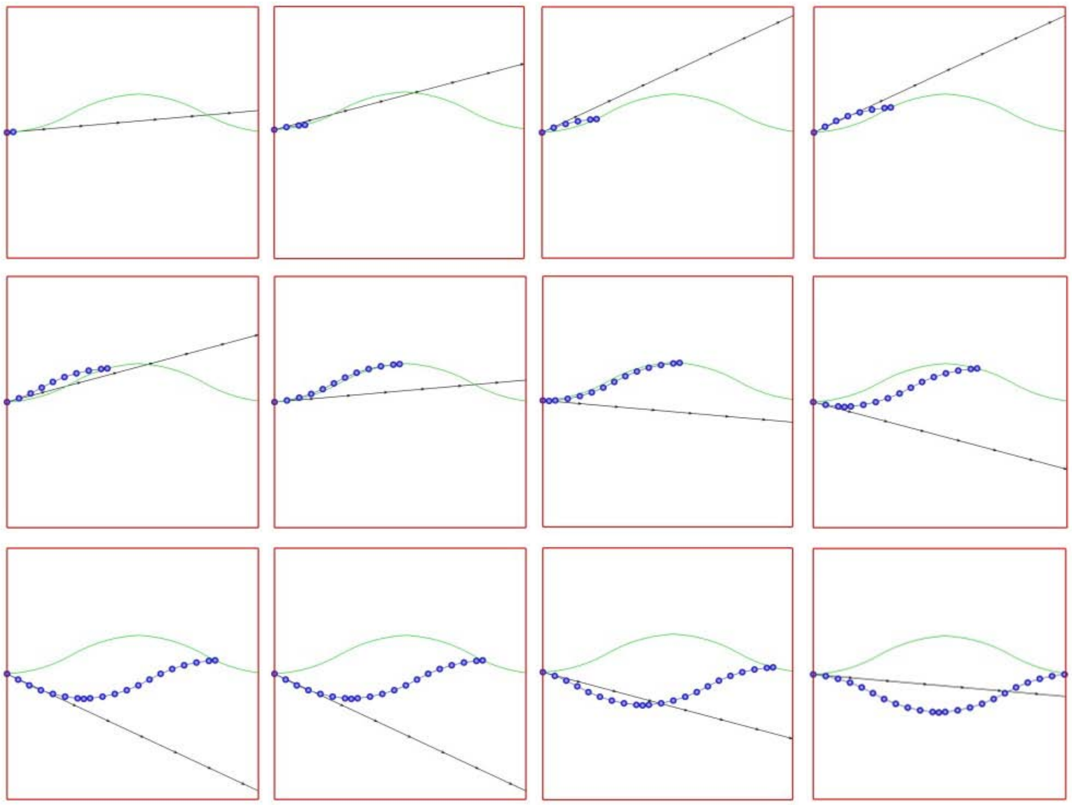
$$\frac{d}{dt}\vec{x}(t) = \vec{v}(\vec{x}(t), t)$$

How is this different from streamlines? Consider the simple example of a vector field whose angle is everywhere oscillating between positive thirty degrees and negative thirty degrees. Streamlines are the direction a particle would take if the vector field were *frozen* at a given time. If you animate over time, the streamline remains a straight line at each step, but its angle oscillates over time with the angle of the vector field.

A particle path for this vector field, on the other hand, is a single static line that has a sinusoidal waviness. If you animate a particle path over time, it doesn't change, because it *already* represents the particle's path over time.

In a three-dimensional vector field, then, a particle path is a four-dimensional space-time line representing the position over time of a particle moving through space. Streamlines are three-dimensional lines which will move during an animation if the velocity field is time-varying.

Streaklines, like particle paths, are derived from the time varying vector field. A streakline is what you get if you *repeatedly* release particles from the same location rapidly enough that they merge together to form a line. An everyday example of a streakline is a thin stream of smoke being released from a chimney. The smoke particles are nearly massless, and they are so numerous that they appear to merge together into a line. Like streamlines, streaklines vary with time. Because streaklines release new particles at each time step, they can be slow to compute.

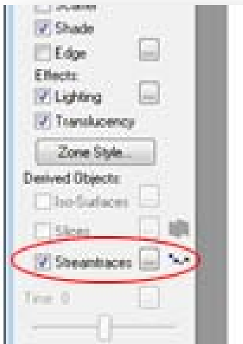


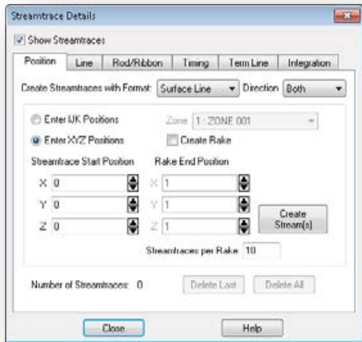
Above is a sequence of images from an animation showing a streamline, particle path, and streakline originating from the same seed point. They are generated using the example vector field whose angle is everywhere oscillating between positive and negative thirty degrees. The streamline is the straight black line whose angle oscillates with the angle of the vector field. The particle path is the unchanging green sinusoidal line which represents the motion over time of a single particle, released at the first time step, as it is pushed by the vector field. The streakline is a blue line, with spherical particles added for clarity. Like the streamline, the streakline also varies with time.

Note that the leading particle of the blue streakline is actually moving along the green particle path. This is because each point on the streakline is a particle released at a different time, with the leading particle released at the starting time. The leading particle, in other words, *is* the particle that whose path is represented by the green particle path.

Clearly, streamlines are of limited use for the analysis of unsteady vector fields. They help visualize the instantaneous vector field, but they tell you nothing of how the vector field is changing over time. Particle paths give a comprehensive view of how the vector field has changed over time (in the regions covered by the particle), but may be difficult to follow for long run times or complicated vector fields. Streaklines provide a useful compromise between the two and have an intuitive physical analog, that of smoke lines.

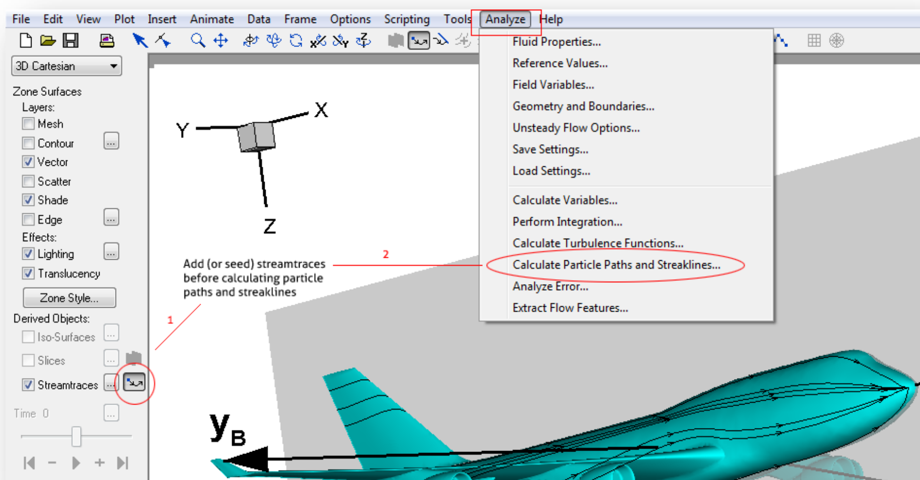
Taking advantage of streamlines, streaklines, and particle paths in Tecplot 360





If you are a Tecplot 360 user, you can turn on streamlines (called streamtraces in the software) for your plot from the sidebar. After activating streamtraces, click on the "..." button to the right to view and edit the streamtrace settings.

To add particle paths and streaklines, 1) add (or seed) your streamtraces and then 2) choose the "Calculate Particle Paths and Streaklines" option from the **Analyze** menu.



More detailed information on using streamlines, streaklines, and particle paths is available in the Tecplot 360 Help.