

Flow Visualization

Thermal, Fluids, and Energy
Systems Lab

(ME EN 4650)

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Department of Mechanical Engineering
University of Utah

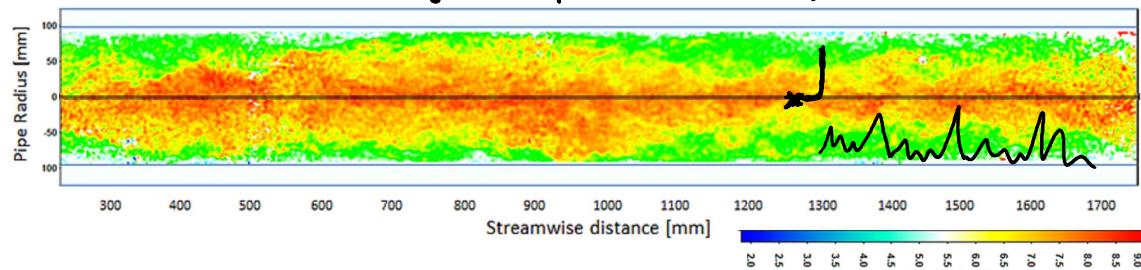


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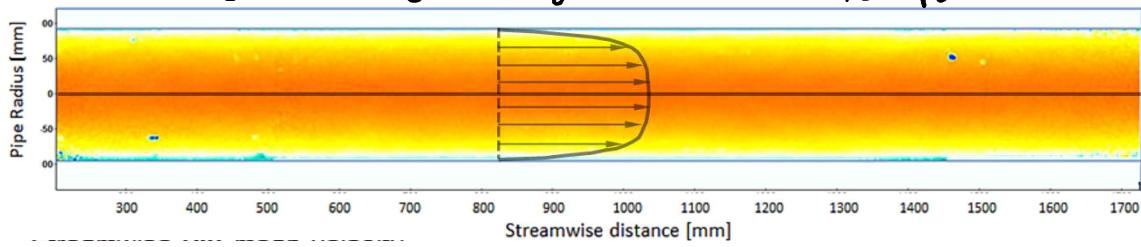
Steady vs Unsteady Flow

Particle Image Velocimetry (PIV): Turbulent Flow through a Pipe

Instantaneous → unsteady: flow properties change in time at fixed pt



Time-Averaged → steady: velocity is constant at fixed pt



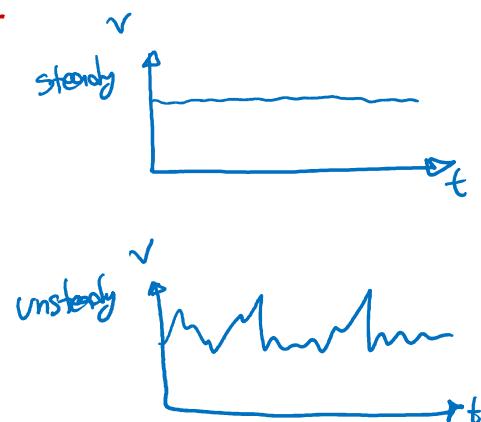
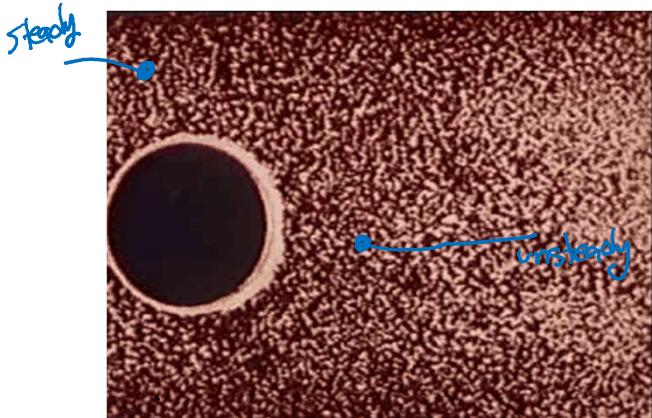
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Steady vs Unsteady Flow

Flow Around a Circular Cylinder



Vortex Shedding



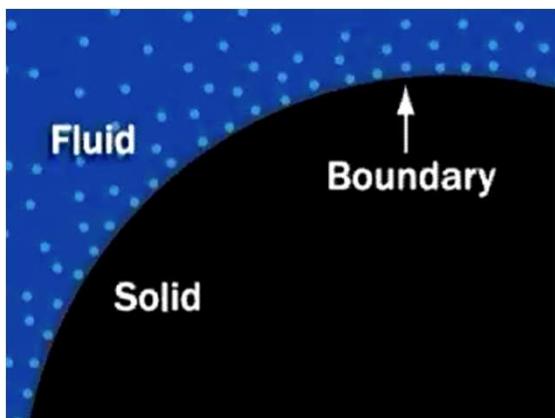
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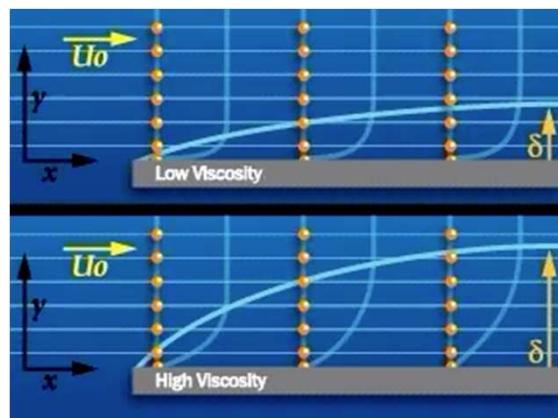
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Flow Near a Solid Surface

No-Slip Condition



Boundary Layer

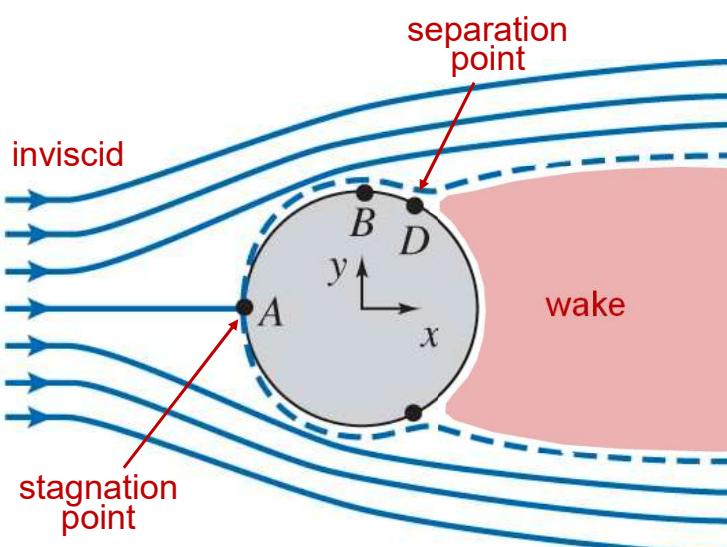


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Separation and Wake



inviscid: viscous effects are negligible

Stagnation point: velocity approaches zero and pressure is maximum

Separation point: shear stress @ surface is zero

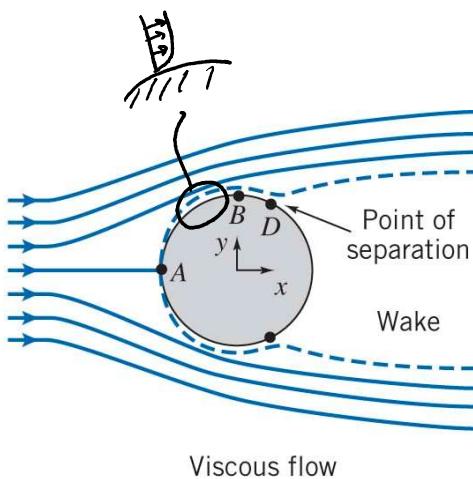
wake: separated, low pressure, unsteady flow behind obstacle.

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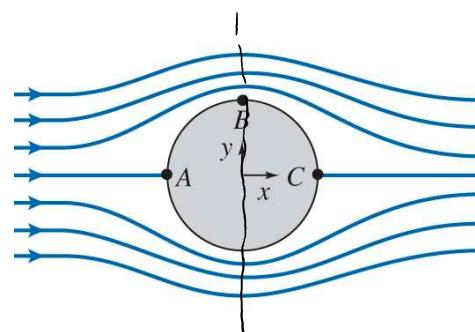
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Inviscid vs Viscous Flow



Viscous flow



Inviscid flow

same pattern observed in creeping flow
($Re < 1$)

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Very Viscous Flow: $Re \ll 1$

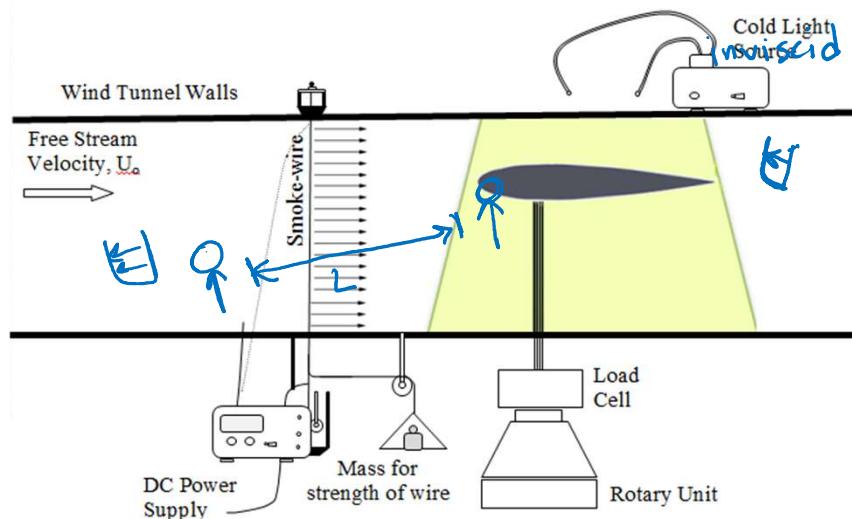


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Reattachment



Streaklines

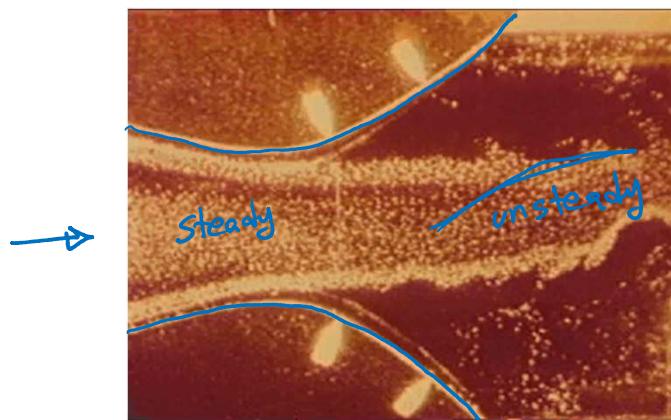
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Flow Separation

Flow through Diverging Channel with and without Suction



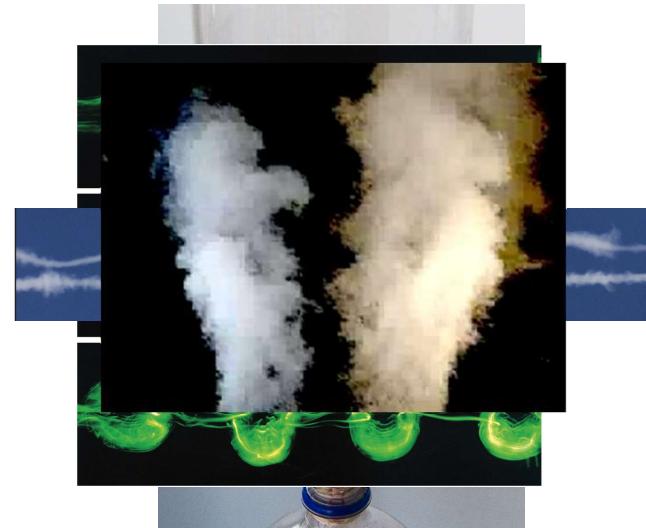
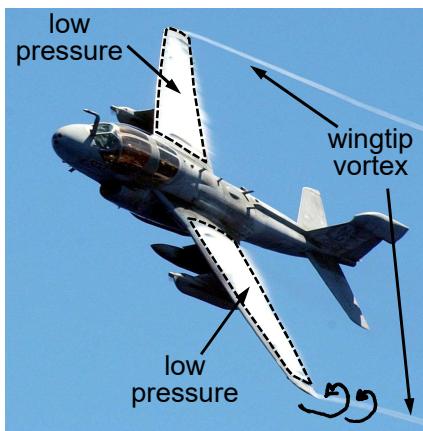
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Vortices

Water Vapor Condensation Visualization



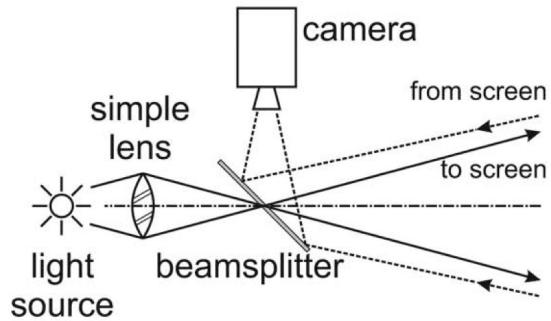
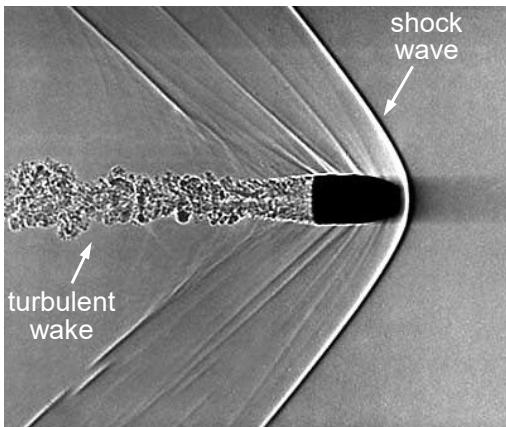
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Supersonic Flow

Shadowgraph Technique



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Laminar vs Turbulent Flow

Shadowgraph Technique

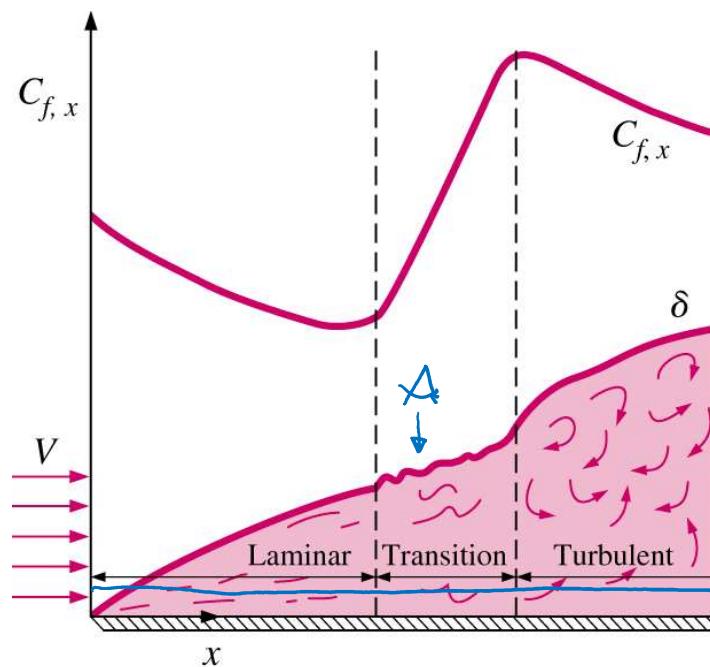


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Transition to Turbulence in a Boundary Layer



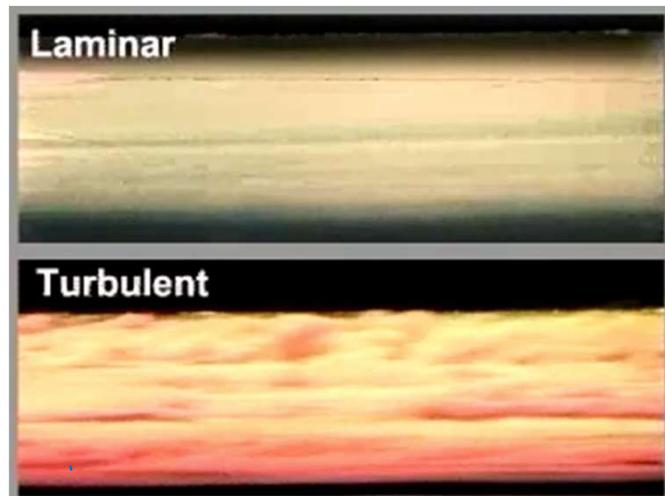
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Laminar vs. Turbulent Flow

Smoke Injection

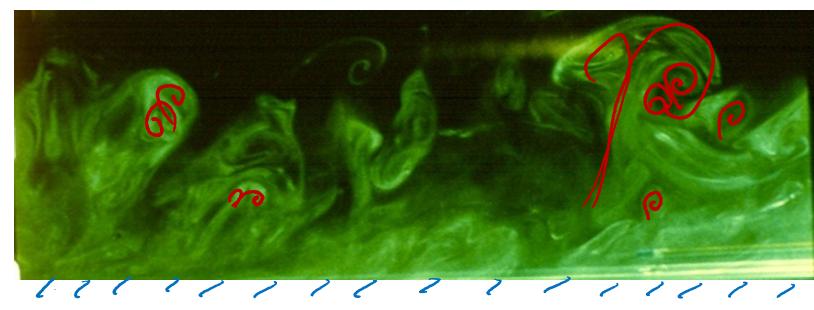
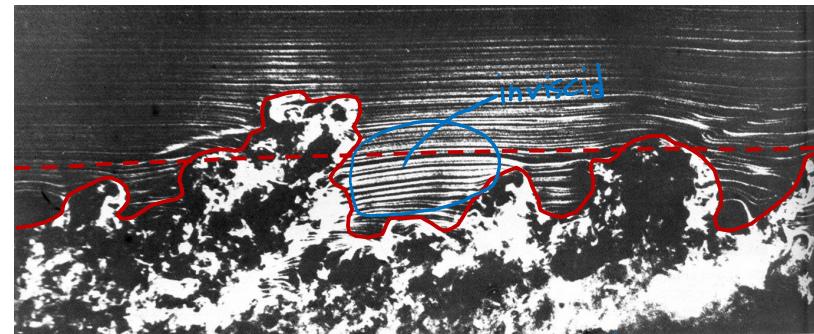


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Smoke Visualization of Turbulent Boundary Layer



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Reference Frames

Lagrangian reference frame

- Tracking the position of individual fluid “particles”
- Closed system approach to analysis (no mass moves across boundaries of system)
- Difficult to do experimentally

Eulerian reference frame

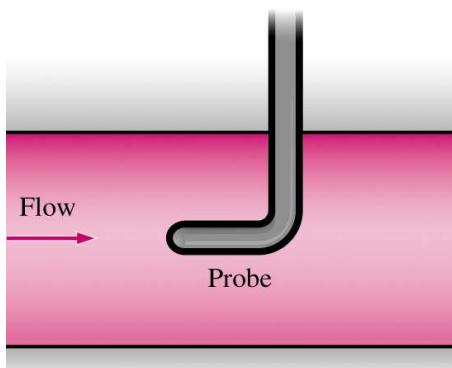
- Control volume approach to analysis (fixed region of space, mass can flow in and out of region)
- Define field variables that are functions of space and time within the control volume
- Much easier to do experimentally with fixed probes



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Lagrangian or Eulerian Measurement?



Stationary probe in an unsteady flow

Eulerian, since the probe is fixed in space

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Lagrangian or Eulerian Measurement?



Buoy drifting in the ocean

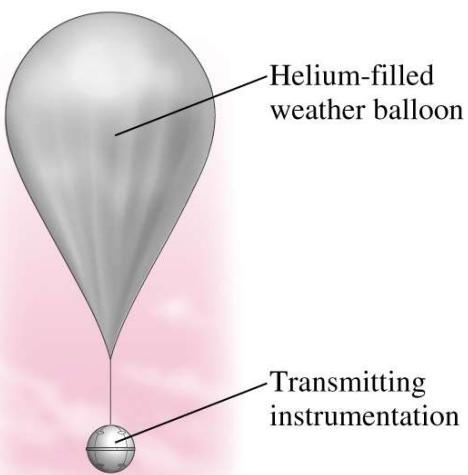
Lagrangian, since the buoy follows the ocean currents

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Lagrangian or Eulerian Measurement?



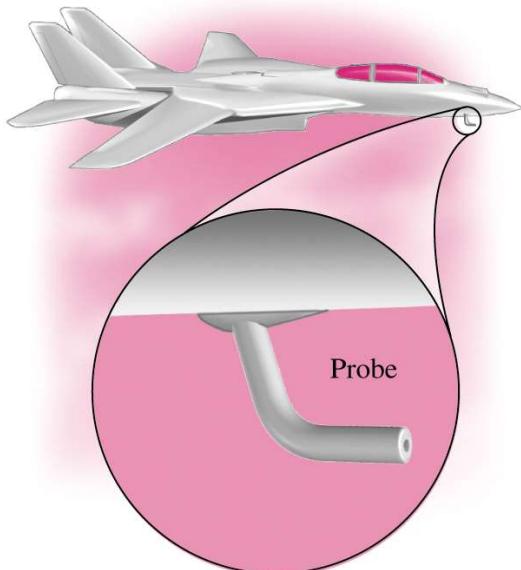
When a weather balloon reaches an altitude where it is neutrally buoyant, it transmits information about weather conditions

Lagrangian, because the balloon is neutrally buoyant it tracks the flow, albeit on a “large” scale

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Lagrangian or Eulerian Measurement?



Wind speed measurement using a probe fixed to an airplane

Eulerian, the probe does NOT follow fluid particles as they move, but remains fixed to the airplane

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Flow Lines

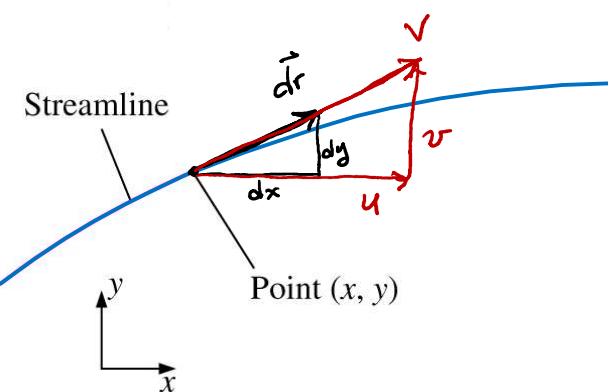
- Streamlines
- Pathlines
- Streaklines
- Timelines



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Streamlines



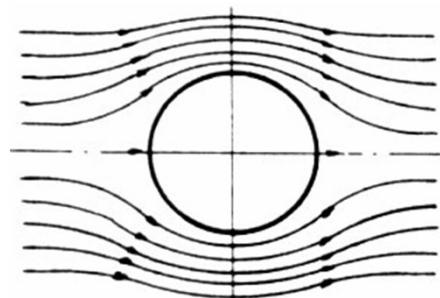
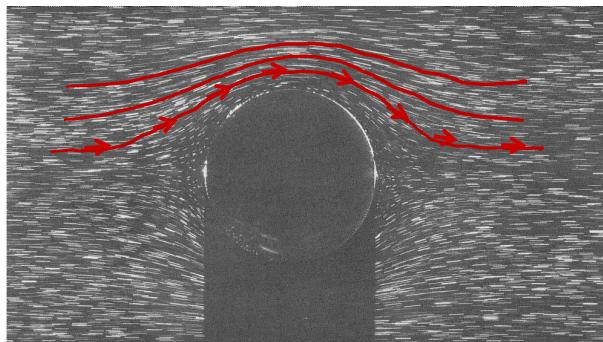
Streamline: a line that
is everywhere tangent
to the velocity field

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Streamlines: Short time-lapse photography of particle motion

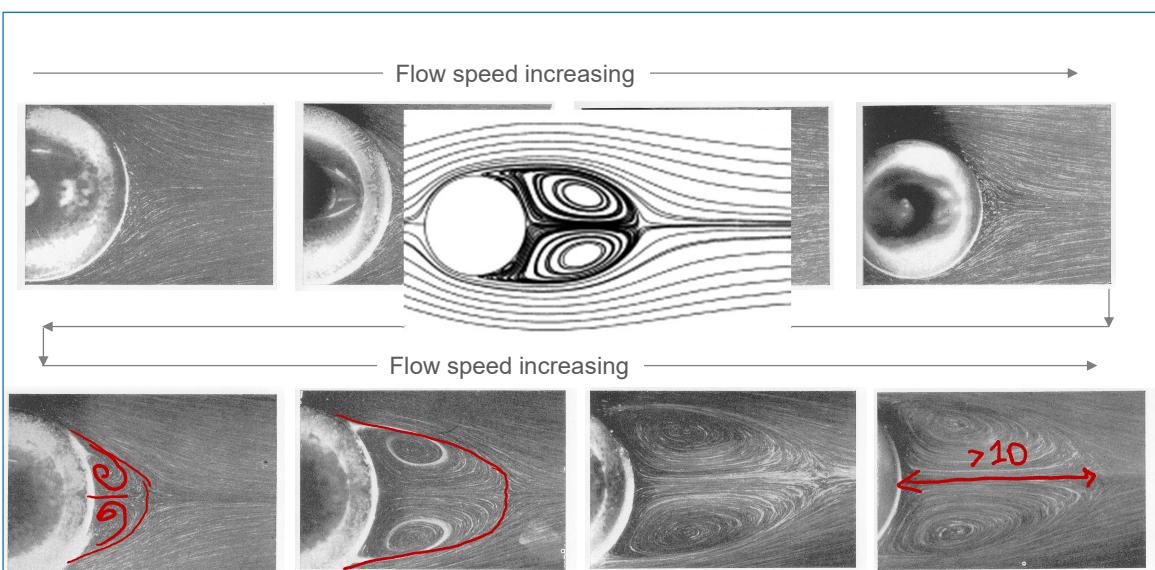


Streamline pattern deduced
from flow visualization image

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Flow Over a Circular Cylinder: Experimental

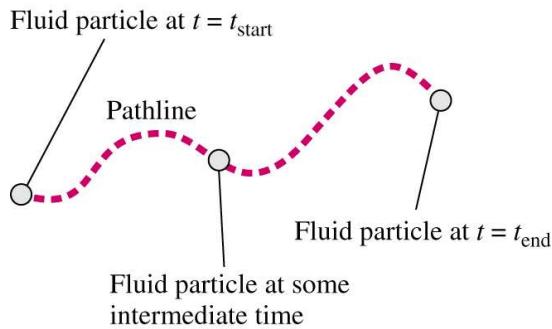


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Pathlines



Pathline: the path or trajectory traced out by a single moving fluid particle.

$$\vec{x} = \vec{x}_{\text{start}} + \int_{t_{\text{start}}}^t \vec{V} dt$$

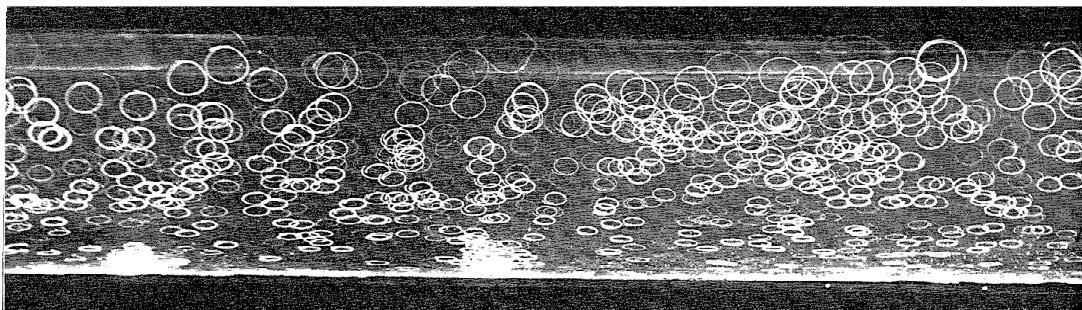
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Pathlines

Gravity wave propagating from left to right

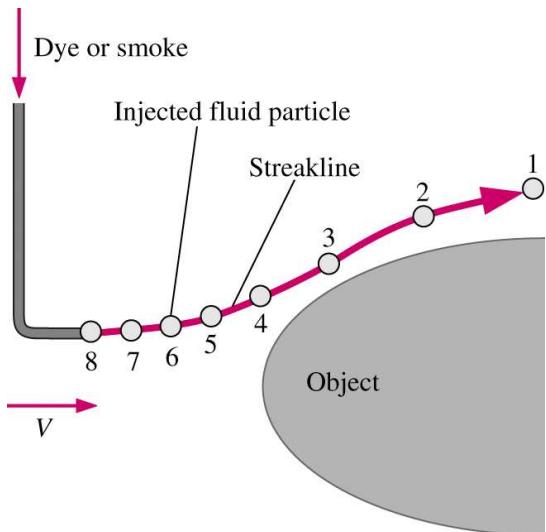


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Streaklines



Streakline: a line joining all of the fluid particles that passed through a fixed point in the flow field at some previous time.

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Dye Injection

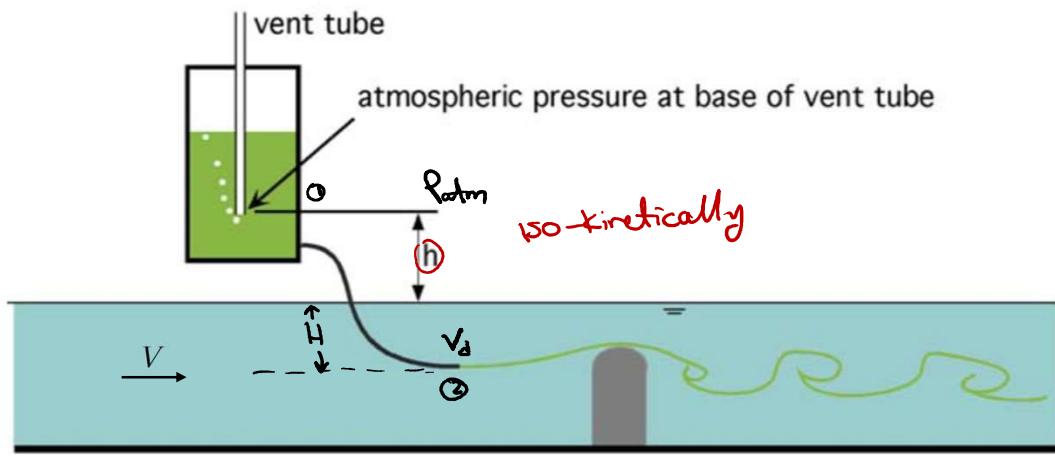
- Neutrally buoyant
- High stability against mixing
- Good visibility
- Non-toxic

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Mariotte Bottle



$$P_1 + \frac{1}{2} \rho V_1^2 + \rho g (h+H) = P_2 + \frac{1}{2} \rho V_2^2 + \rho g H$$

$$P_{atm} + \overset{O}{\rho g (h)} + \cancel{\rho g H} = P_{atm} + \rho g H + \frac{1}{2} \rho V_d^2$$

$$V_d = \sqrt{2gh}$$

want $V_d = V$

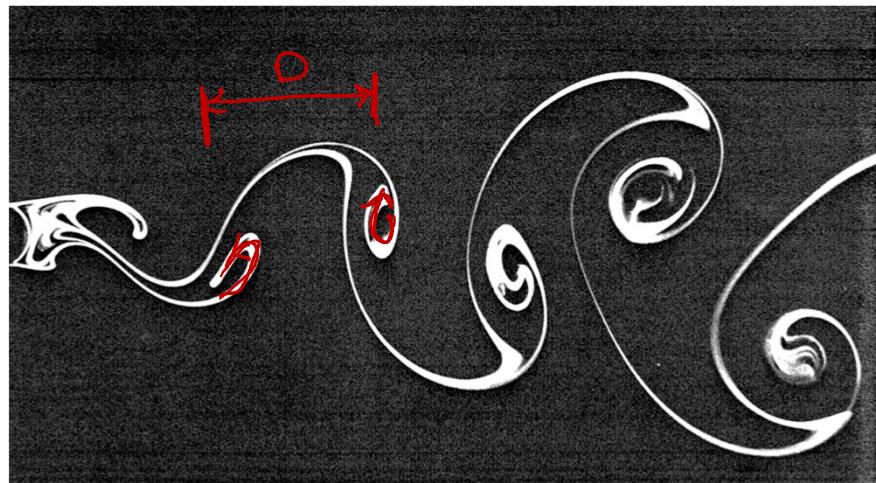
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Streaklines

Vortex Street behind Circular Cylinder

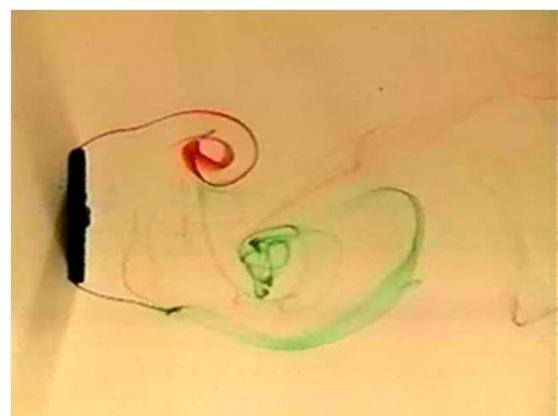


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Streaklines

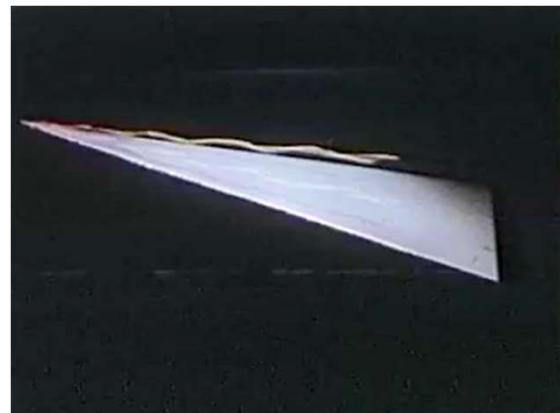


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Streaklines

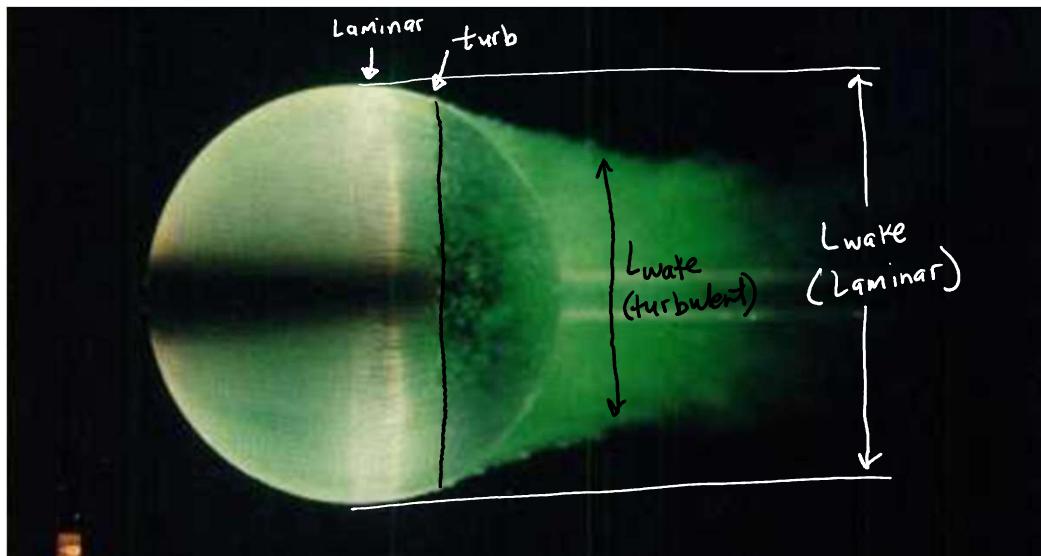


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Dye Visualization



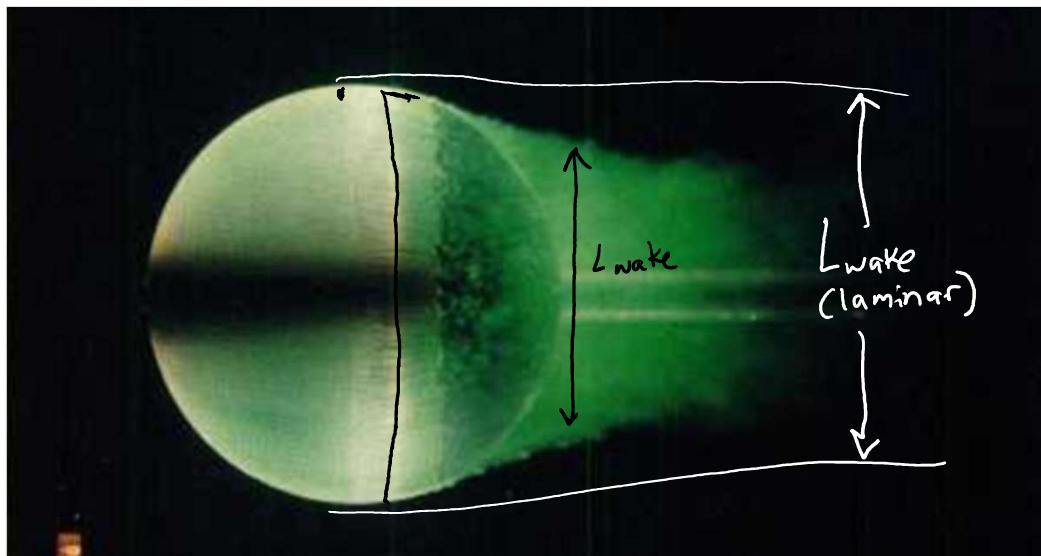
$$Re_0 \approx 3 \times 10^5$$

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Dye Visualization

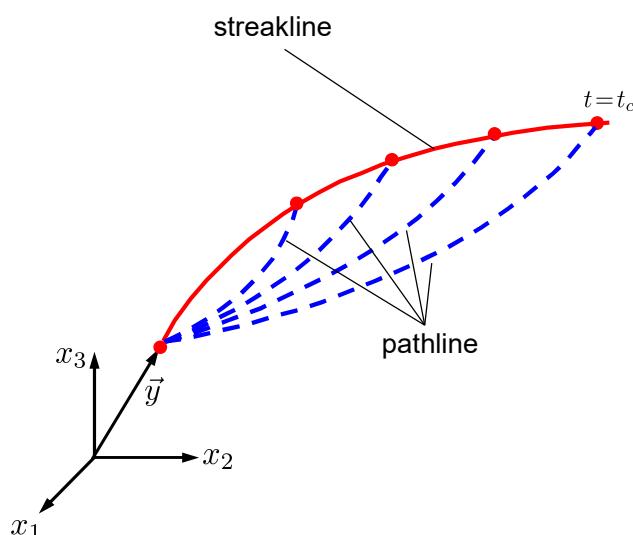


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Streaklines vs Pathlines in Unsteady Flow

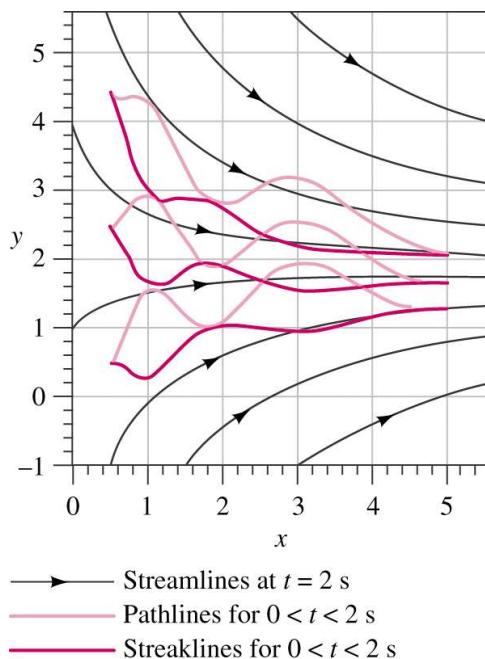


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Comparison of Flow Lines in an Unsteady Flow



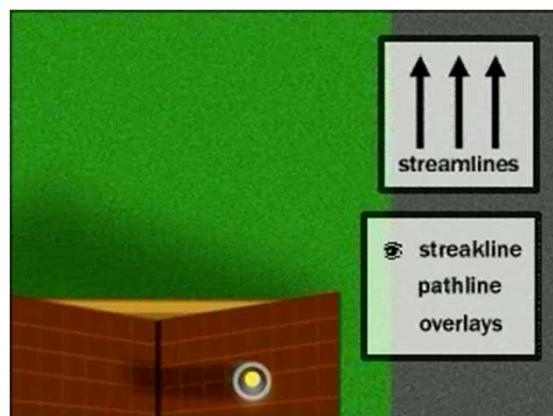
Streamlines, pathlines, and
streaklines only coincide when
flow is **STEADY**

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Comparison of Flow Lines in an Unsteady Flow

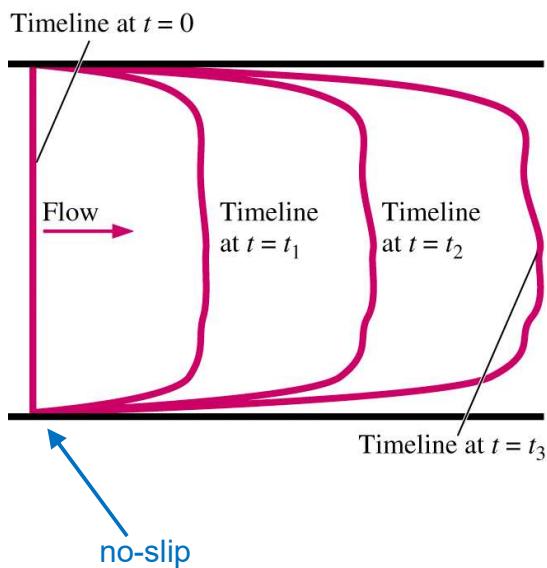


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Timelines



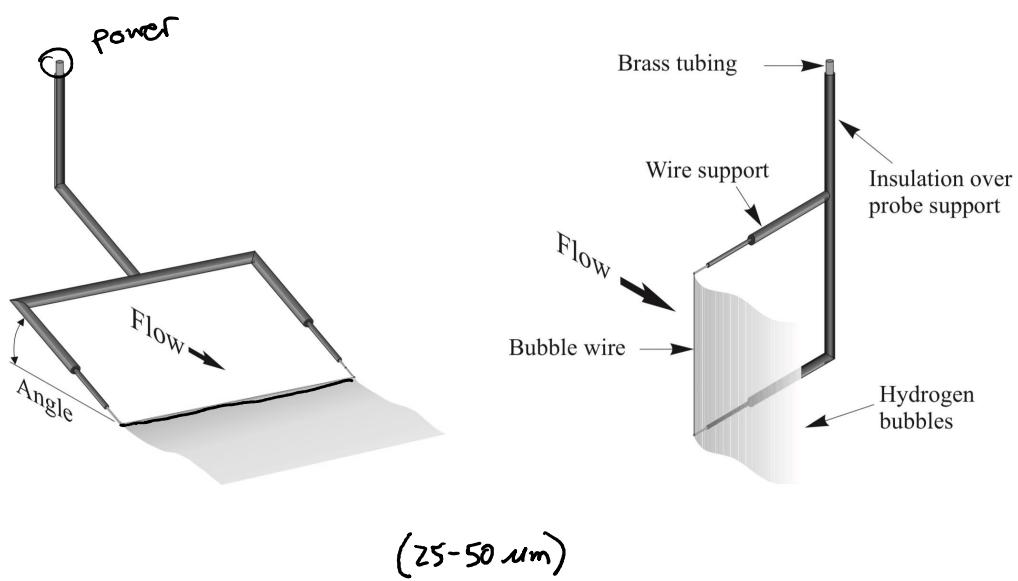
Timeline: a set of adjacent fluid particles that were marked at the same (earlier) instant in time.

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Timelines: Hydrogen Bubble Technique

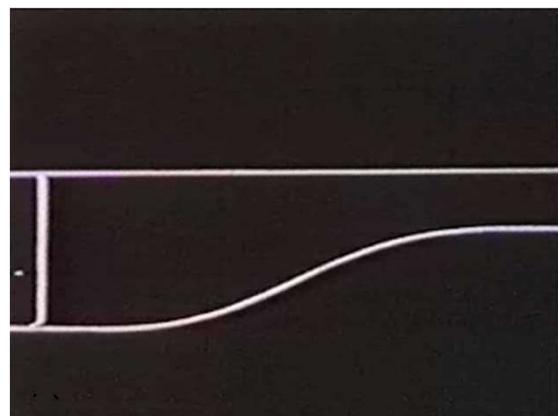


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Timelines: Converging Channel

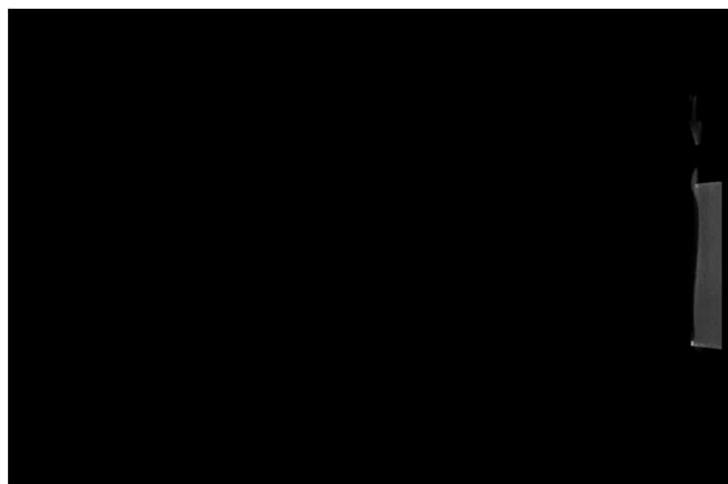


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Vortex Ring



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Vortex Rings in Nature

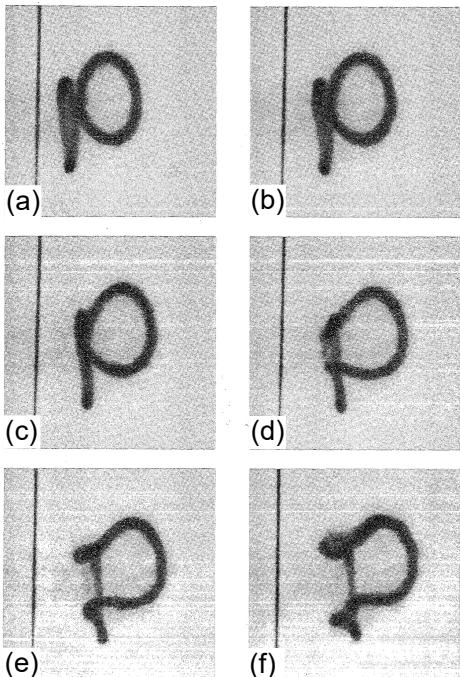


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Merging Vortex Rings

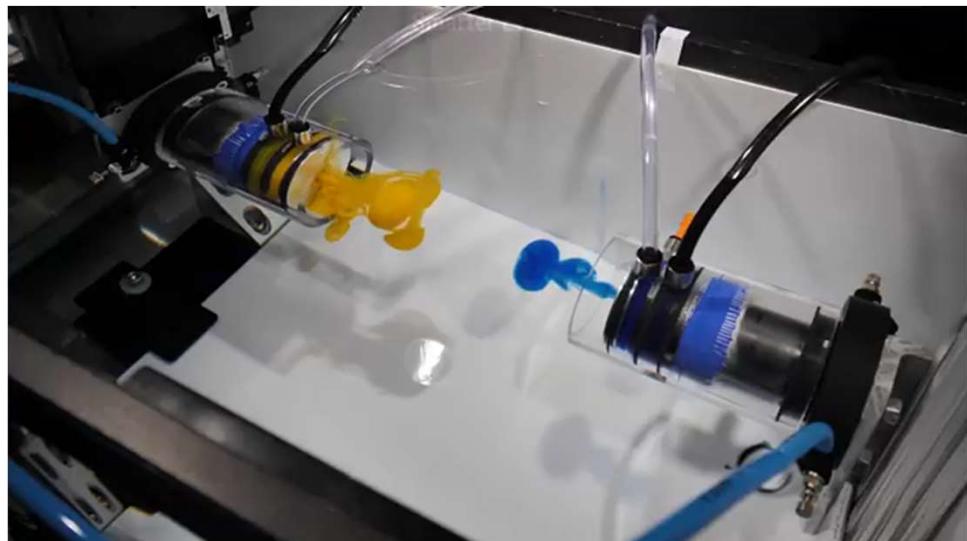


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Colliding Vortices



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Questions??

Thank you for your attention!

Let me or the TAs know if you have questions



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