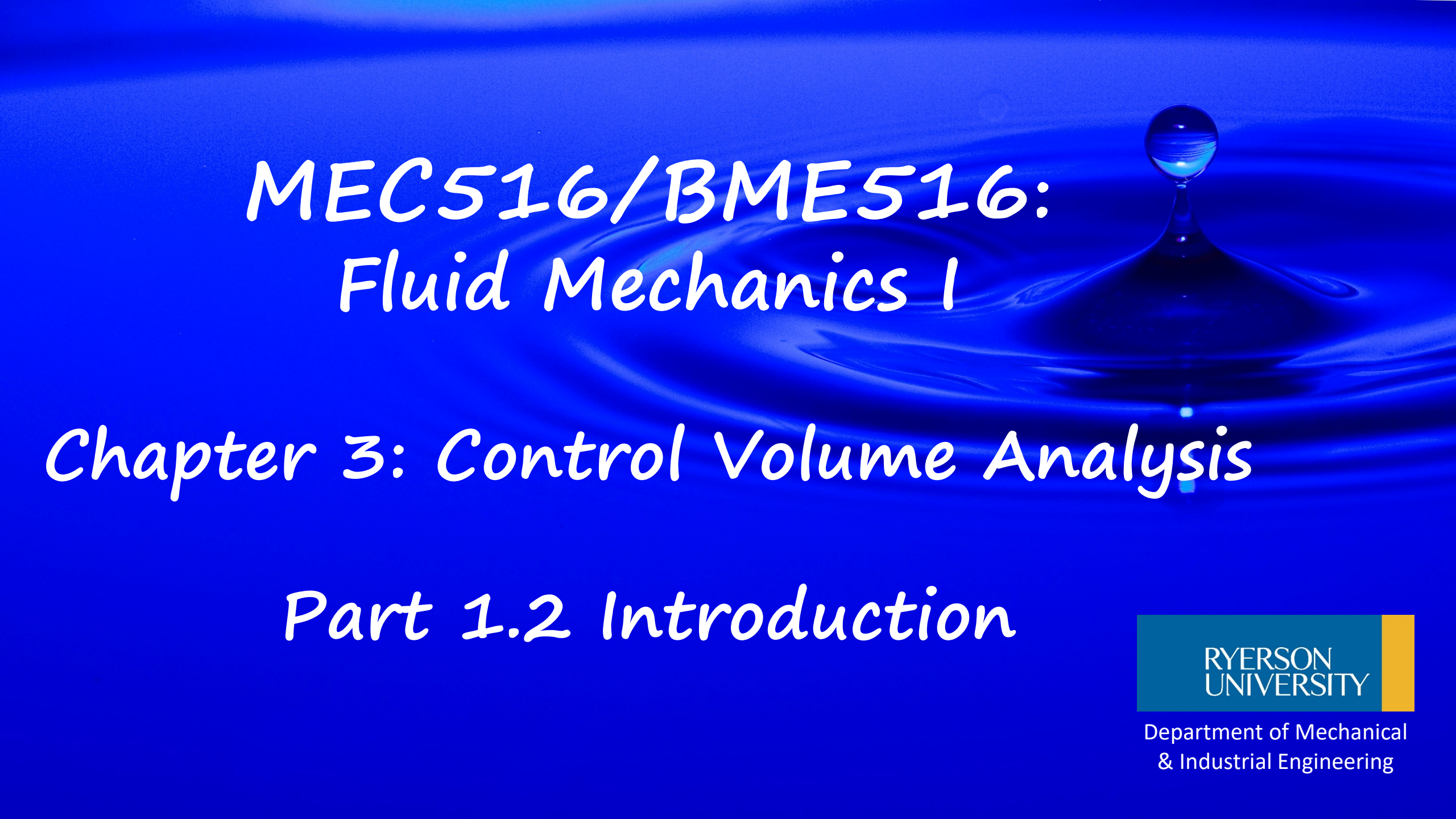


MEC516/BME516: Fluid Mechanics I

Chapter 3: Control Volume Analysis

Part 1.2 Introduction

RYERSON UNIVERSITY
Department of Mechanical & Industrial Engineering

Overview

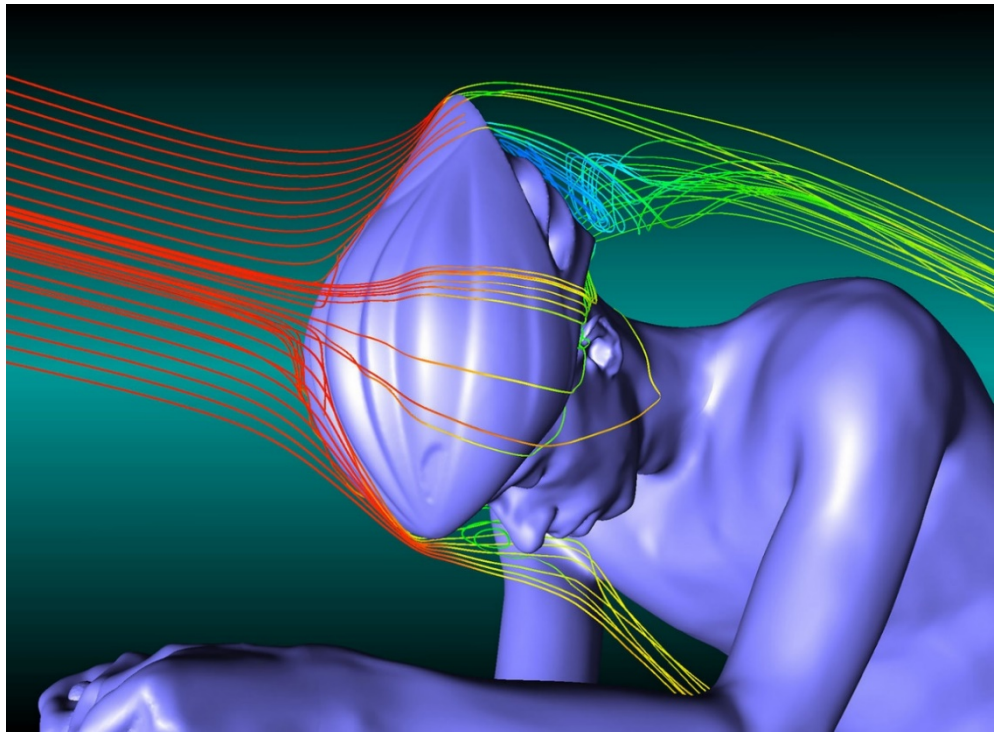
Basic definitions/terminology for Chapter 3:

Part 1.1

- 3-D Vector Representation for Fluid Velocity
- Simplifications: 1-D and 2-D Flows
- Compressible and Incompressible flow

Part 1.2

- Flow Visualization
  - Streamlines
  - Streaklines
  - Pathlines



Fluid flow over a cyclist, obtained by computational fluid dynamics (CFD) software, Fluent.

Photo credit: http://gallery.ensight.com

Flow Visualization: Streamlines, Pathlines and Streaklines

- Fluid dynamics is a highly visual subject. A set of techniques called *flow visualization*
- *Flow visualization* can be experimental or numerical

- Three main types of "lines" used visualize to flow fields:
  - (i) Streamlines
  - (ii) Streaklines
  - (iii) Pathlines

  - All three lines are the same in a steady flow, but different in a transient flow

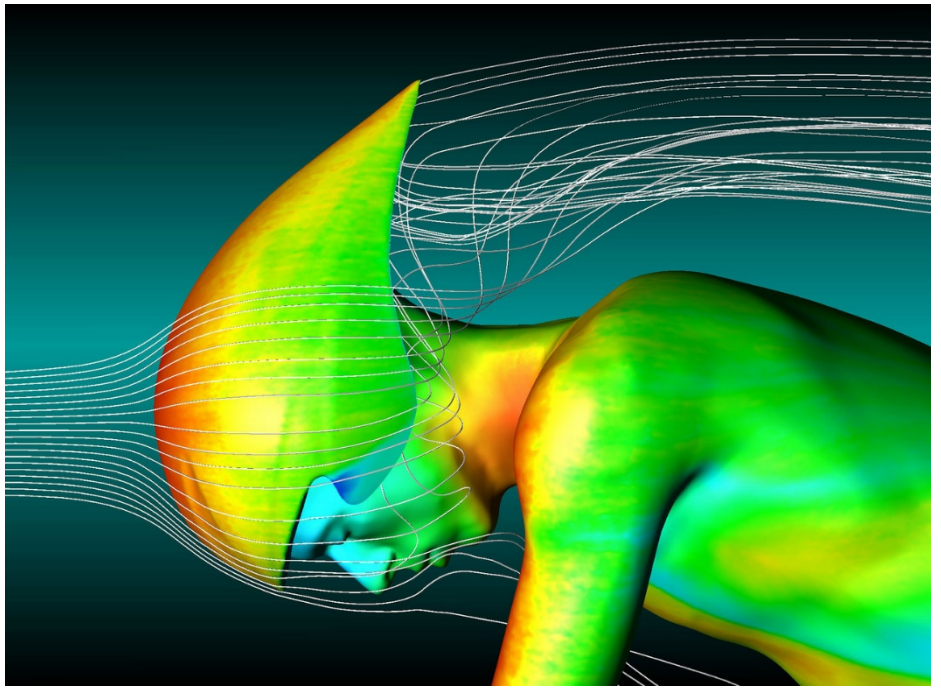
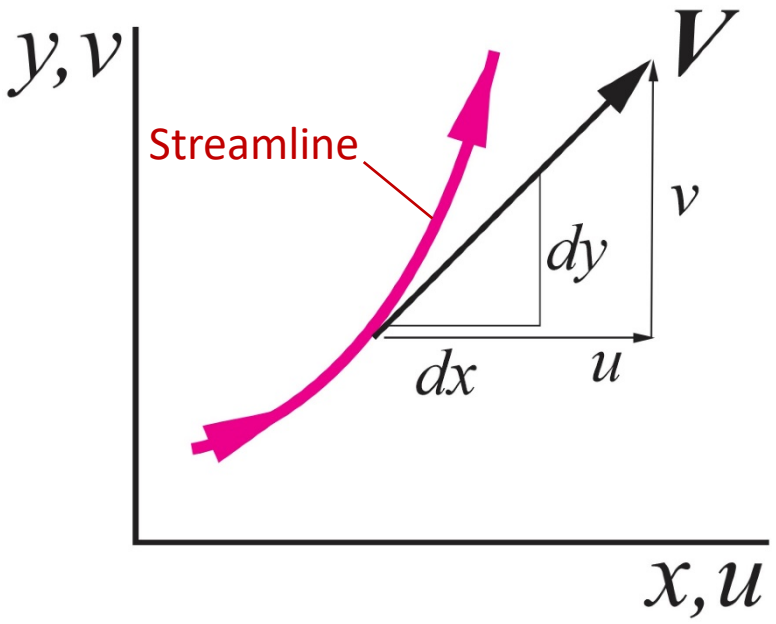
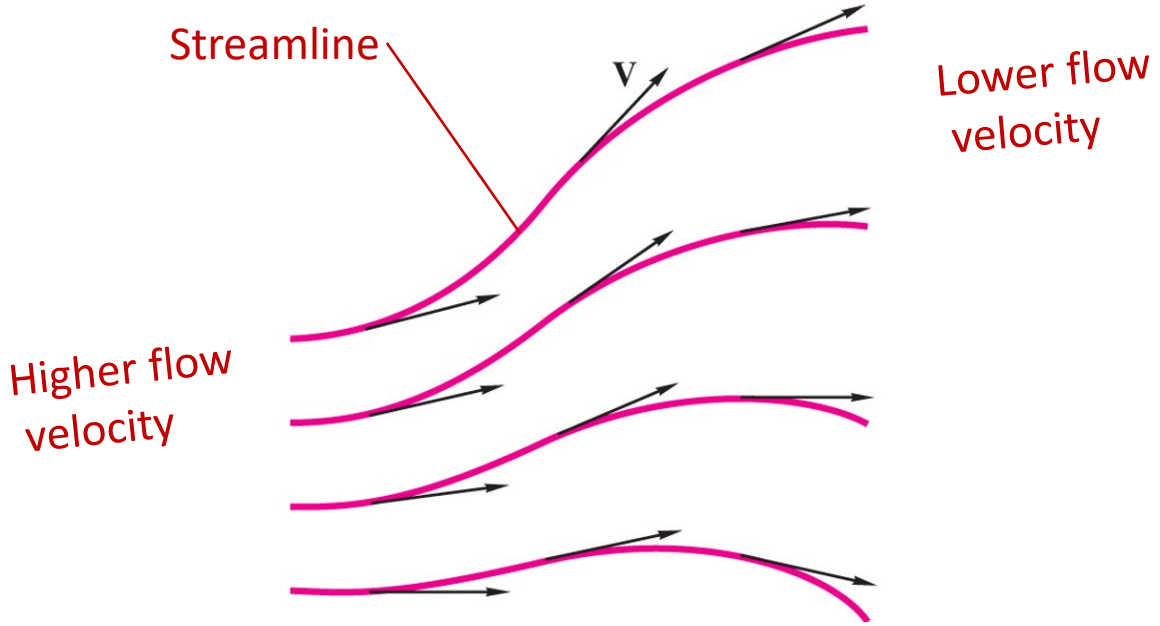


Photo credit: http://gallery.ensight.com

Streamlines

- A *streamline* is a line that is everywhere tangent to the instantaneous velocity field
  - No flow crosses a streamline



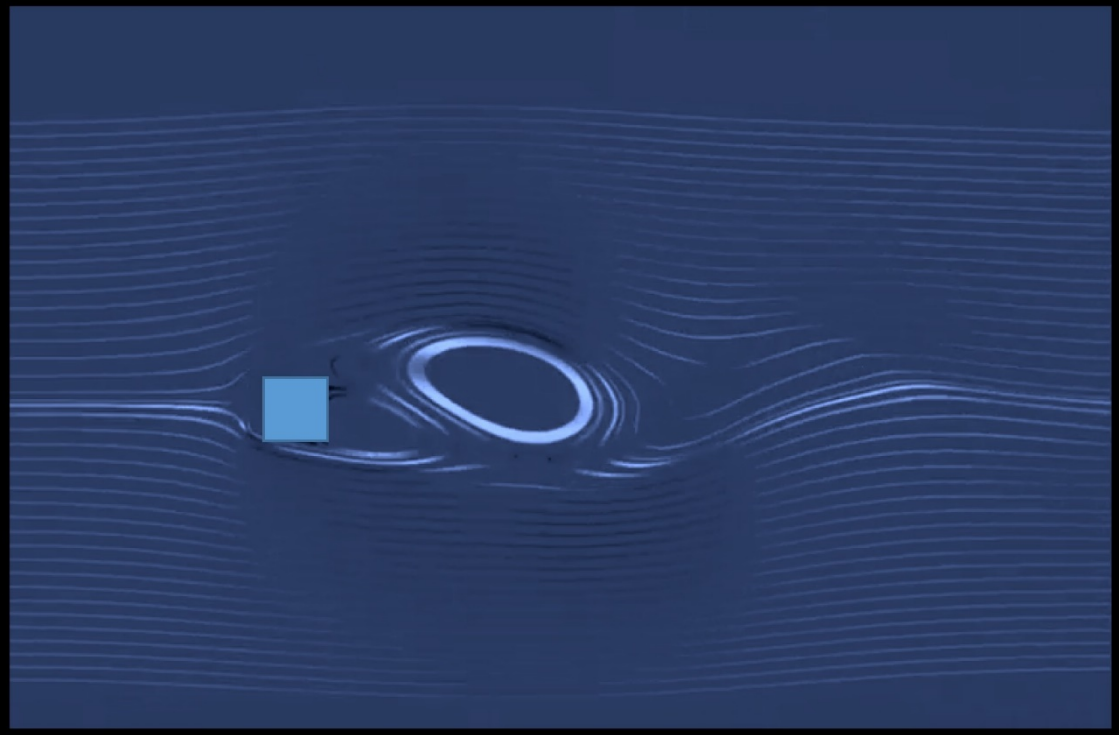


- From similar triangles (2-D flow): $\frac{dy}{dx} = \frac{v}{u}$

Streamlines in an Unsteady 2-D Flow over a Square Cylinder

- Visualization of a Computational Fluid Dynamics (CFD) solution of the flow field
- Unsteady accelerating flow
- Instantaneous streamlines

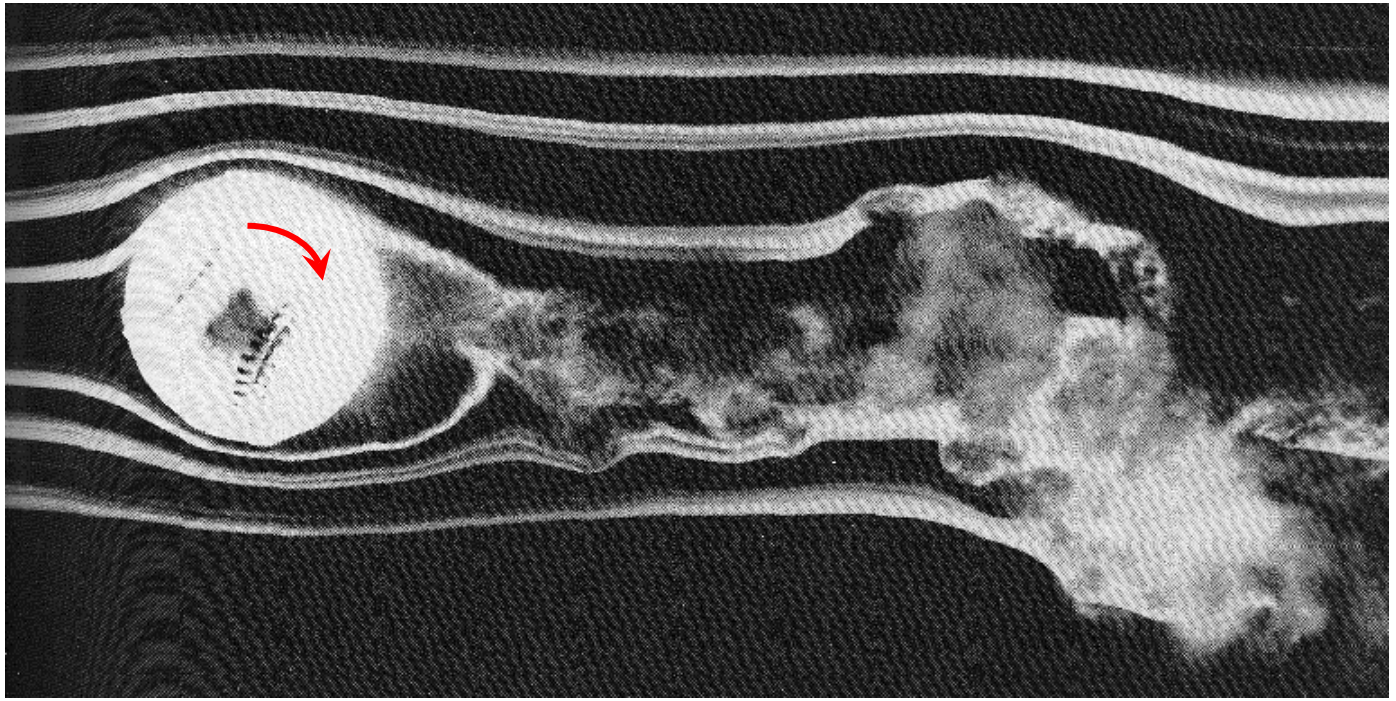
Flow



Streaklines

- A *streakline* is the line produced by fluid particles that have passed through a prescribed point
- In experiments, streaklines are obtained by (isokinetic) injection of smoke into a gas or dye into a liquid
- All the smoke (or dye) passed through a common point, the tip of the injection tube

Flow



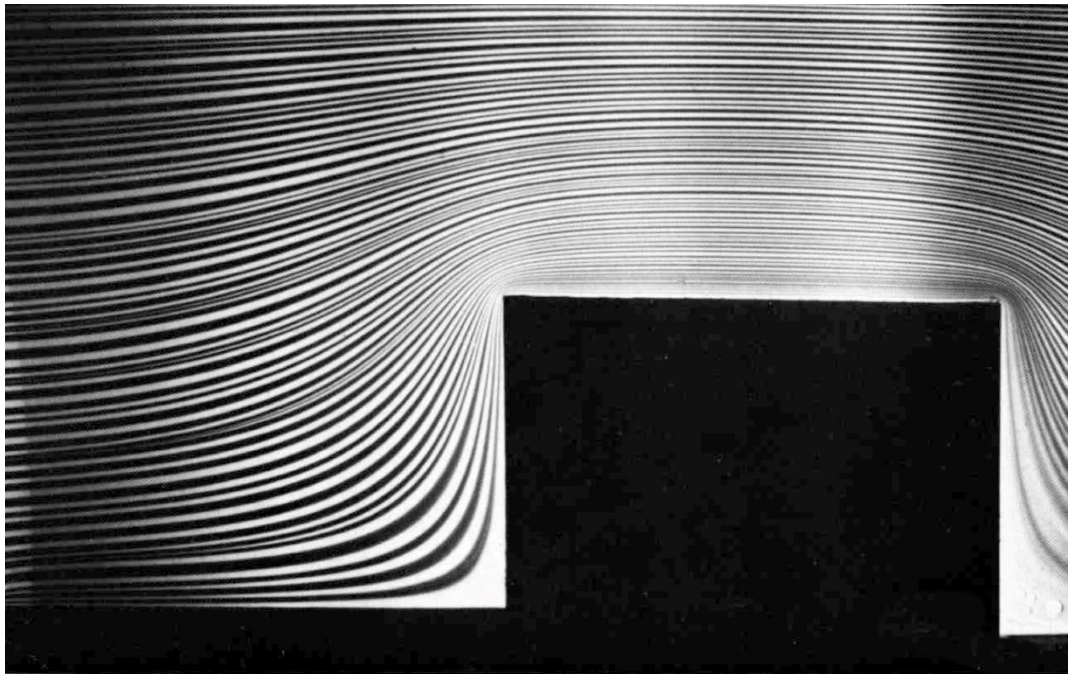
Images shows the “downwash” of air behind a spinning baseball (630 rpm). Ball will curve toward top of image. (Magnus Effect)

Photo Credit: Album of Fluid Motion (Van Dyke 1988)

Streaklines in a Steady Flow

- Dye injection at multiple upstream locations
- In a steady flow streaklines are tangent to the velocity local vector
- Streaklines can be used to visualize streamlines in steady flow

Flow



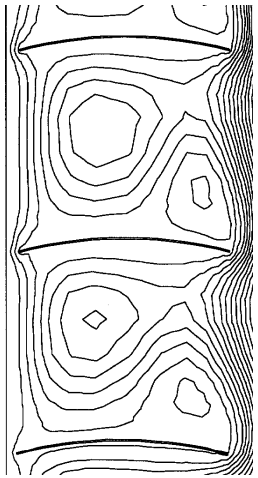
Flow over a block at low Reynolds number

Photo Credit: Album of Fluid Motion (Van Dyke 1988)

Streaklines

- My research on the effect of blinds on the thermal performance of windows
- Streaklines between a louvered blind, near a warm indoor glazing. (Glazing is on left side)
- Smoke injection, plane illuminates with laser
- Steady flow. Thus, streaklines are streamlines
- Excellent for validating computer predictions

Experimental Streaklines



Streamlines in Simulated Flow (CFD)

Pathlines

- A *pathline* is the path of a fluid “particle” through the flow field
- In experiments, pathlines are usually obtained by using long-duration time exposures
- Opening the camera shutter for an extended time. “B” setting on a DSLR
- Image below (unrelated to fluid mechanics) illustrates the technique

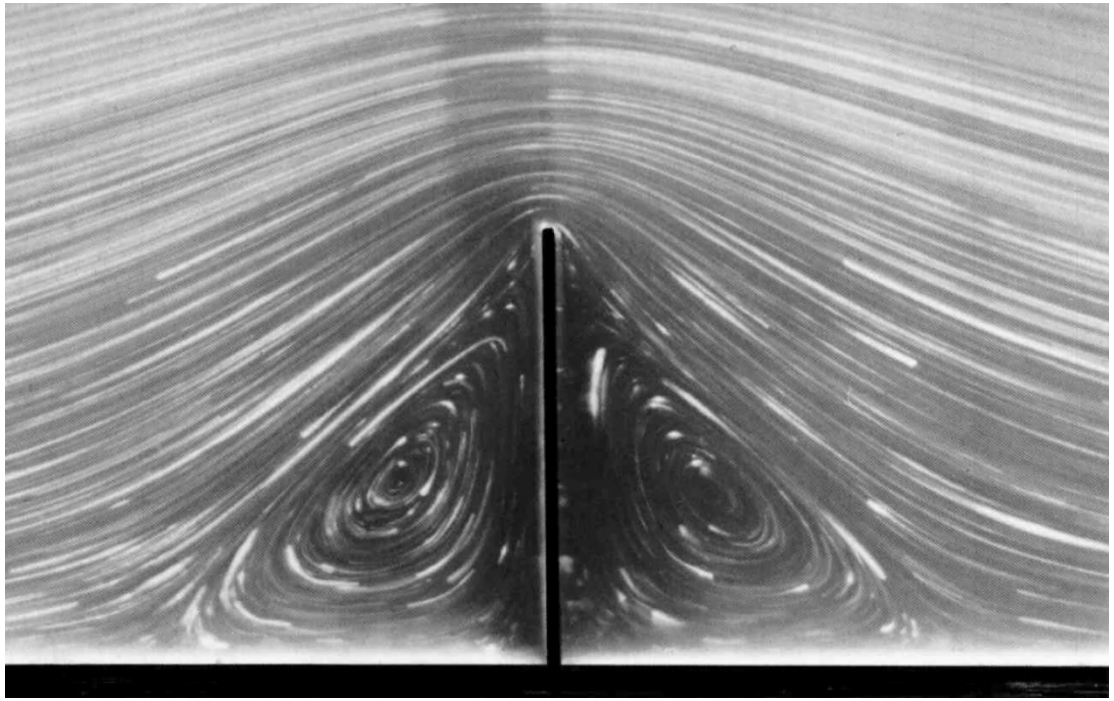
Pathlines of stars (over several minutes) because of the rotation of the Earth.

Photo credit: http://www.hightech-edge.com

Pathlines in a Steady Flow

- Aluminum particles in glycerin
- A time exposure (e.g. 2 seconds) flow over a fence at low Reynolds number
- Shows the particle paths – pathlines are equivalent to streamlines in a steady flow steady

Flow



Flow over a fence at low Reynolds number

Photo Credit: Album of Fluid Motion (Van Dyke 1988)

Pathlines in an Unsteady Flow: Flow Caused by a Wave

- Time exposure of flow in water below a passing wave, for one full wave
- Image shows the pathlines of shiny neutrally buoyant particles
- Particles travel in circles near the surface! **Pathline ≠ Streamlines**

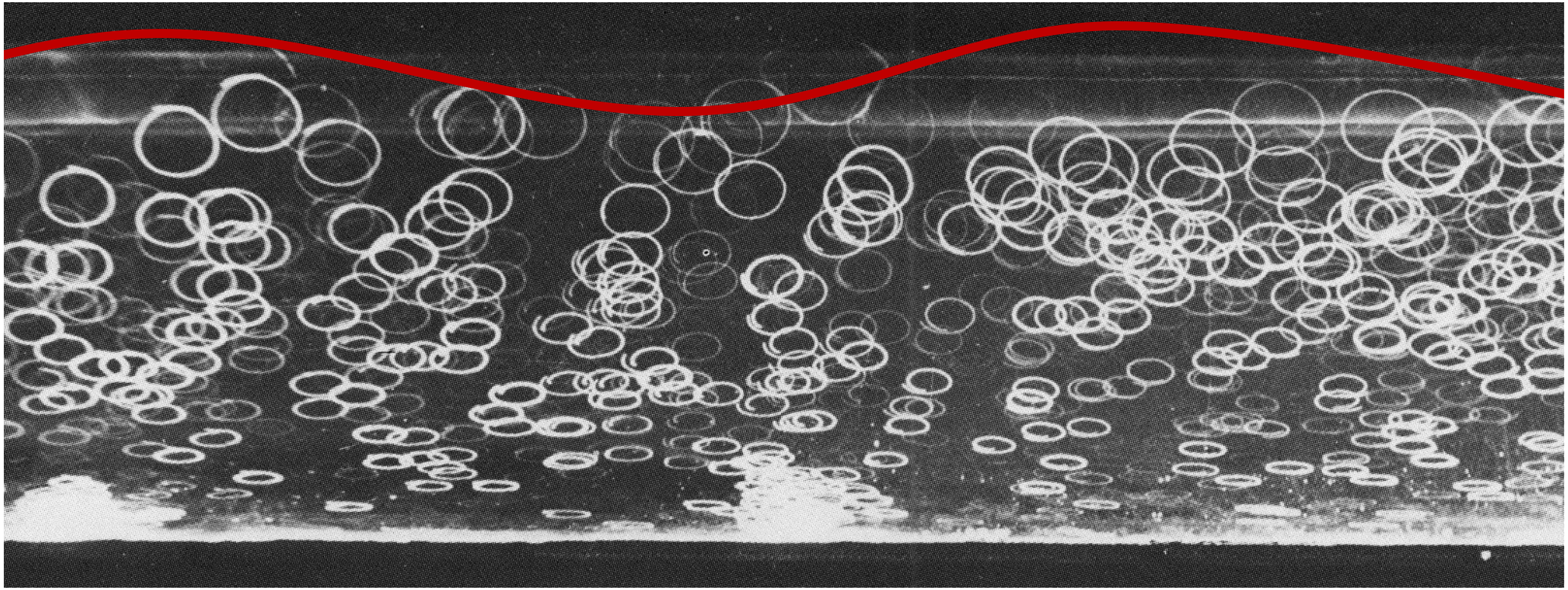


Photo Credit: Album of Fluid Motion (Van Dyke 1988)

US National Committee for Fluid Mechanics Film

- Excerpts from the 1963 Film “Flow Visualization”
  - Excellent visual demonstration that streaklines and pathlines are **not** streamlines in unsteady flow!

Credit https://youtu.be/nuQyKGuXJOs

Streaklines over a car (Credit: www.gifycat.com)

The “Magnus Effect” on a spinning ball (Credit: www.gifycat.com)

END NOTES

Presentation prepared and delivered by Dr. David Naylor