MEC516/BME516: Fluid Mechanics I

Chapter 3: Control Volume Analysis

Part 1.1 Introduction

RYERSON UNIVERSITY
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Overview

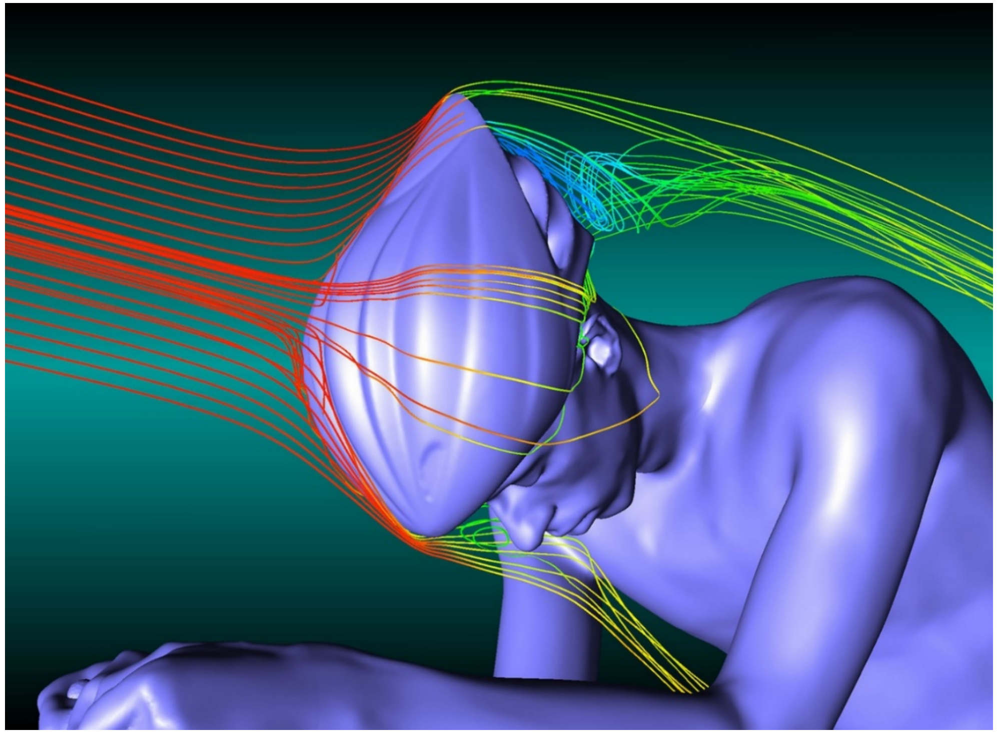
Basic definitions/terminology for Chapter 3:

Part 1.1

- 3-D Vector Representation for Velocity Field
- Simplifications: 1-D and 2-D Flows
- Compressible versus Incompressible Flow

Part 1.2

- Flow Visualization
  - Streamlines
  - Streaklines
  - Pathlines

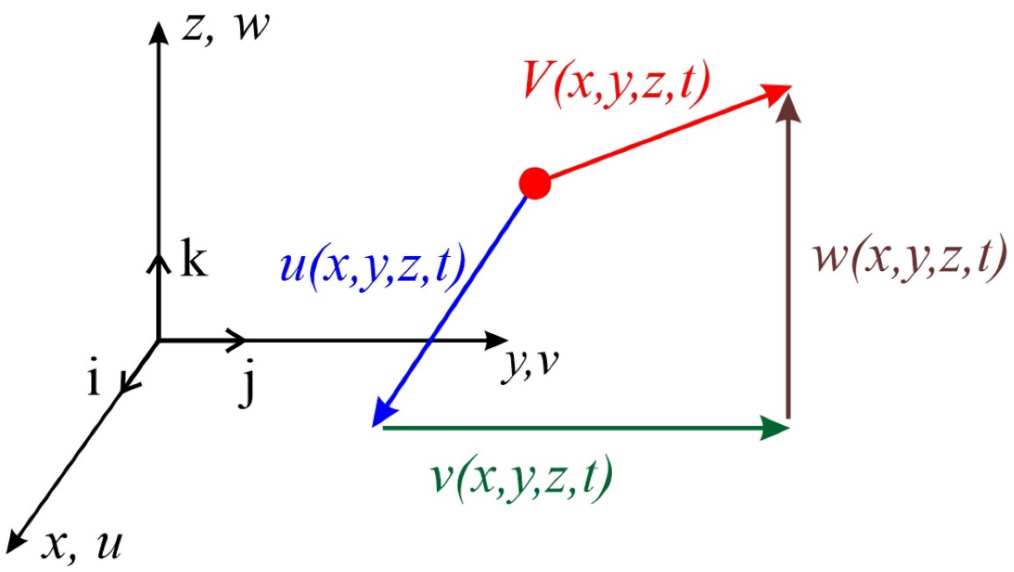


Fluid flow over a cyclist, obtained by computational fluid dynamics (CFD) software, Fluent.

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

Velocity Field

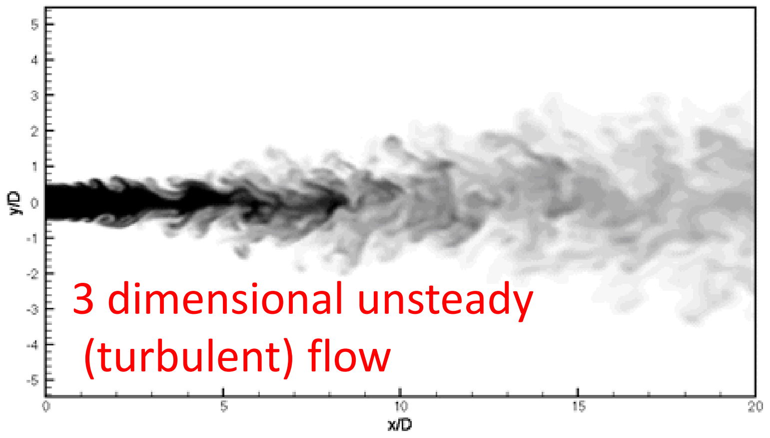
- Vector field representation of the flow



- The velocity vector field in Cartesian co-ords:

$$\boldsymbol{V} = \mathbf{i}\, u(x, y, z, t) + \mathbf{j}\, v(x, y, z, t) + \mathbf{k}\, w(x, y, z, t)$$

where *u, v* and *w* are the velocities in the x, y, and z directions

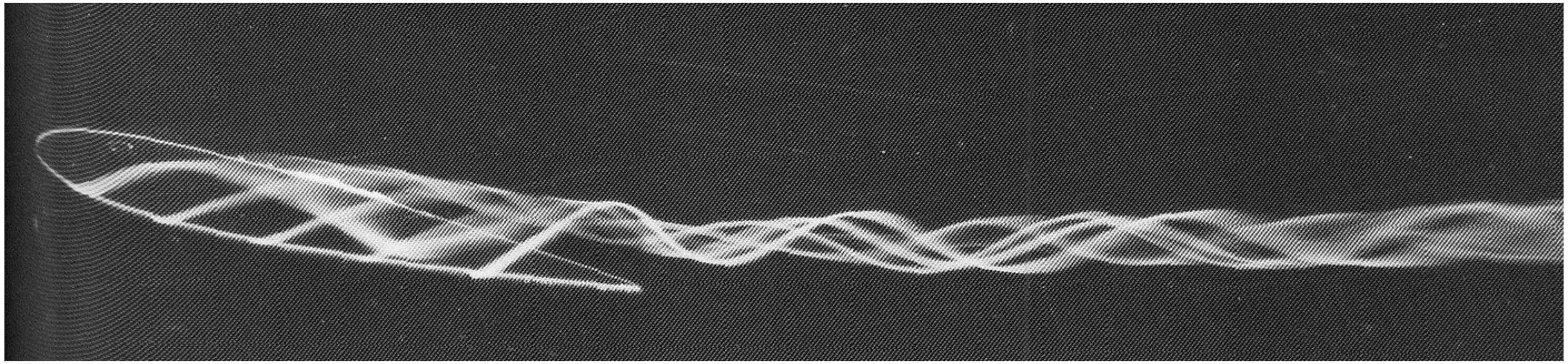


- If V depends on time, the flow is *transient* or *unsteady*
- If V has no time dependence, the flow is *steady*

Three-Dimensional Flow

- Most real flows are three dimensional. Velocity varies in spatial 3 co-ordinates
- Velocity vector: $\boldsymbol{V} = \mathbf{i}\, u\underbrace{(x, y, z, t)}_{\text{3-D}} + \mathbf{j}\, v(x, y, z, t) + \mathbf{k}\, w(x, y, z, t)$
- The flow at the end of a wing is highly three-dimensional

Flow

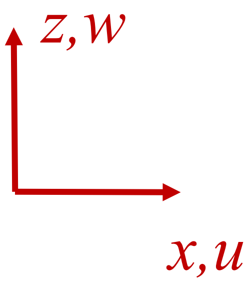


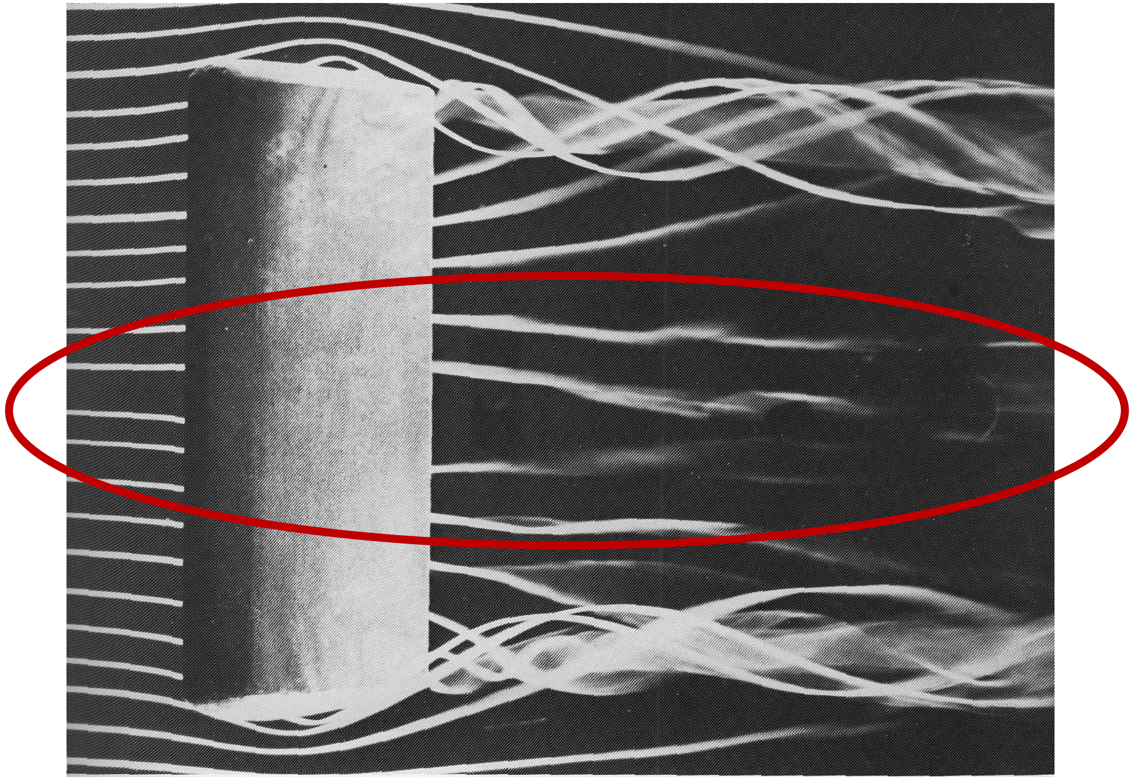
3-D flow over an airfoil showing a wing tip vortex

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

Two-Dimensional Flow

- 2-D Velocity vector field: $\boldsymbol{V} = \mathbf{i}\,u(\overbrace{x,y}^{\text{2-D}},t) + \mathbf{j}\,v(x,y,t) \quad (w = 0)$
- In the centre portion of the wing, the flow may be approximated as two-dimensional





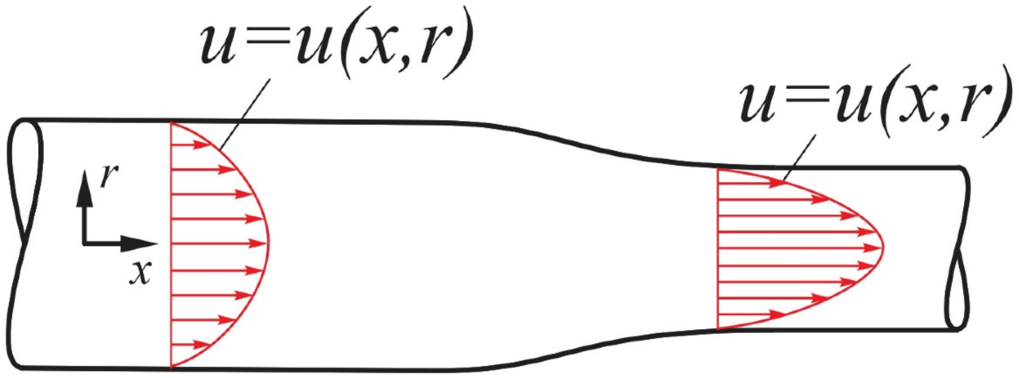
2-D flow region ($w \approx 0$)

Top view of flow over an airfoil, showing the wing tip vortices.

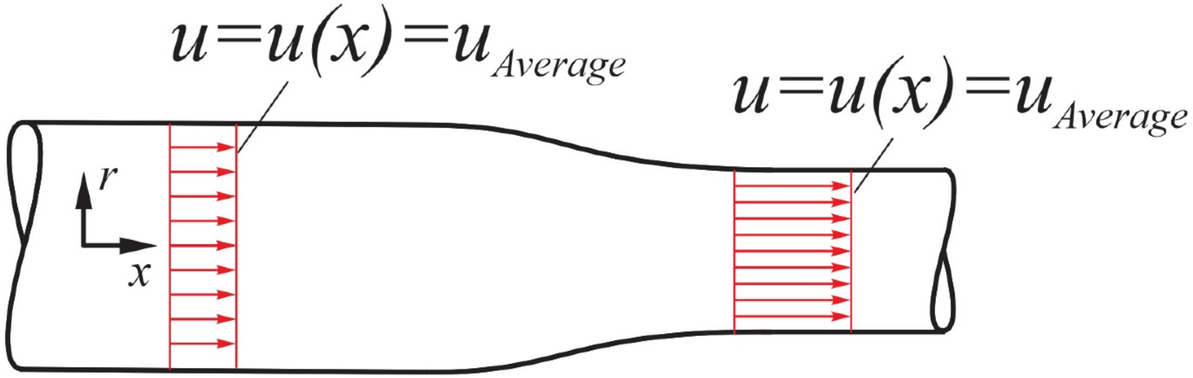
Photo Credit: Album of Fluid Motion (Van Dyke 1988)

One-Dimensional Flow

- Velocity vector field: $V = \mathbf{i}\, u(x) \quad (v = w = 0)$
- It is often useful to approximate a flow as one-dimensional
- 1-D approximation is commonly used in pipe flow, shown below
- Will use this approximation in Chapter 3 (e.g. the Bernoulli Equation)



Actual 2-D Flow



1-D Approximation of the Flow

Compressible and Incompressible Flow

- Liquids are generally considered incompressible, i.e. density (ρ) is constant
- Low speed gas flow can also be approximated as incompressible
- Rule of thumb: Gas flows will be compressible for Mach number, $Ma > 0.3$

Mach Number: $Ma = \frac{V}{c}$ V is the gas speed, c is the speed of sound in the gas

$$Speed\ of\ sound \quad c = \sqrt{kRT}$$

$c \approx$ 340 m/s for air at room conditions

The photo of supersonic bullet was taken by physicist Ernst Mach 1888! This is a compressible flow -- air density is not constant Mach is famous for studying shock waves

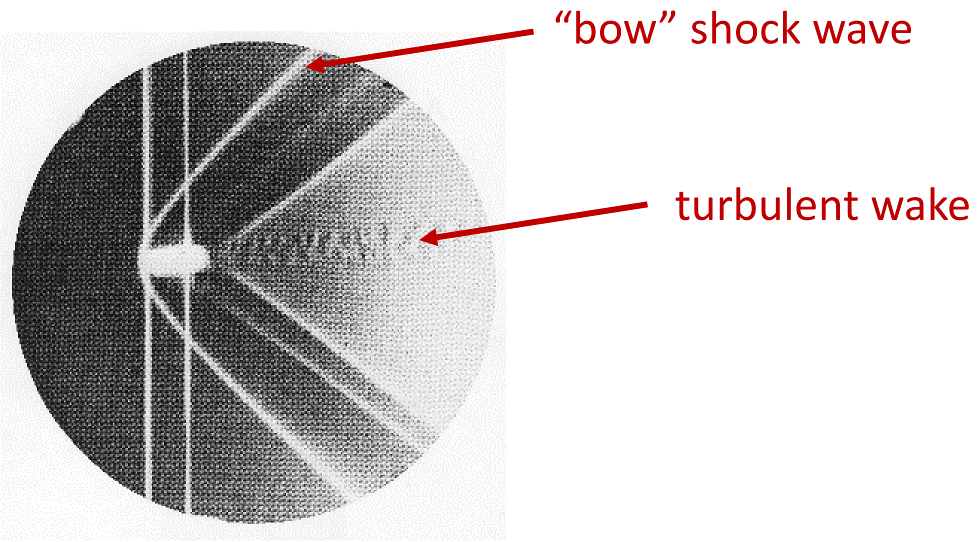
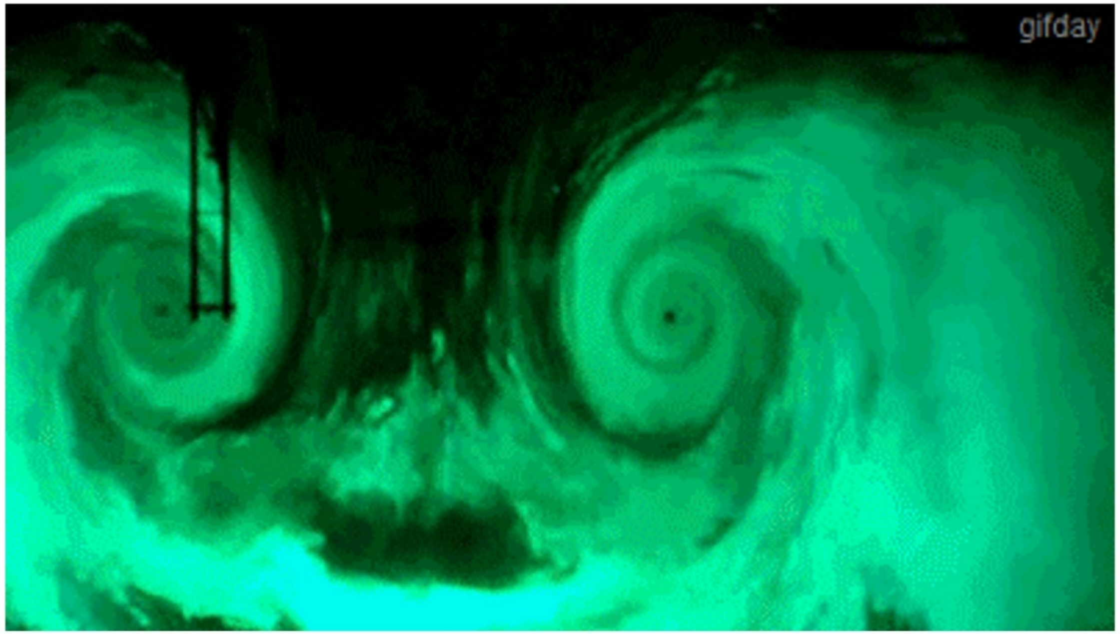
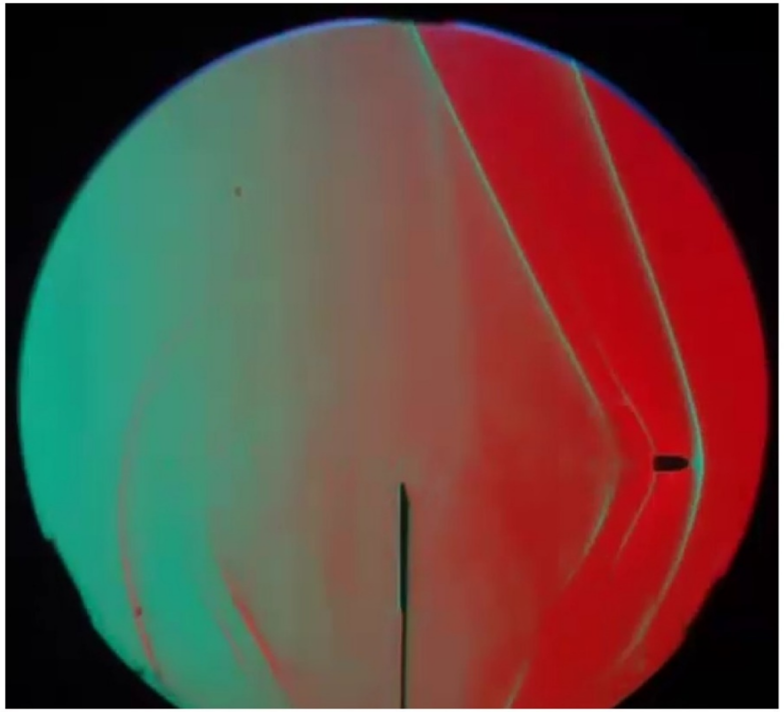


Photo Credit: Album of Fluid Motion



Credit: https://www.tumblr.com/tagged/fluid-dynamics



Credit: https://youtu.be/GWqAUQQ1Hqk

END NOTES

Presentation prepared and delivered by Dr. David Naylor