Teach Poiseuille First:

Call for a Fluid Dynamics Paradigm Shift

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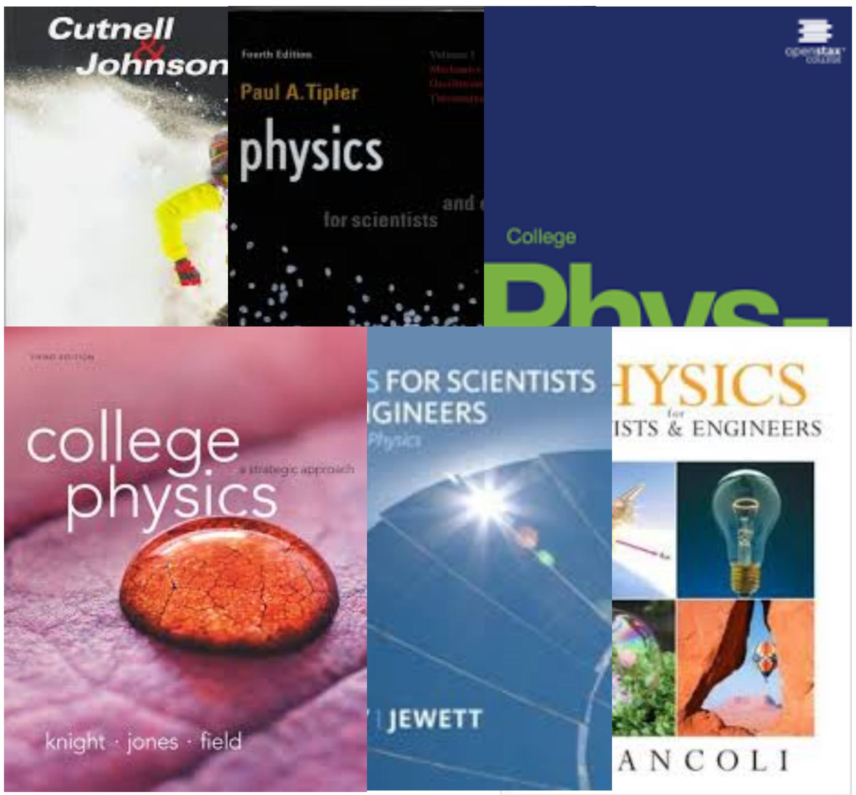
AAPT PHYSICS EDUCATION

UNE UNIVERSITY OF NEW ENGLAND

Traditional Fluids

Standard textbooks…	…and their coverage of fluids



- Static fluids
  - Buoyancy
  - Hydrostatic pressure
- Dynamic fluids
  - Continuity
  - Bernoulli equation
- If time permits
  - Viscosity and Poiseuille's law

IPLS Fluids applications

For Premed majors

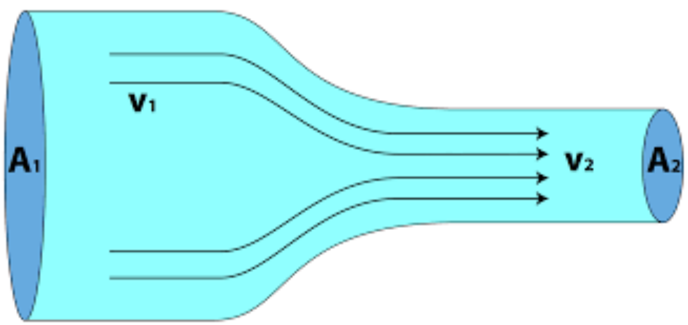
- Static pressure
  - In body (“hydrostatic”)
  - In cells (surface tension)
- Dynamic pressure
  - Circulatory system
  - Respiratory system
  - Flow restriction

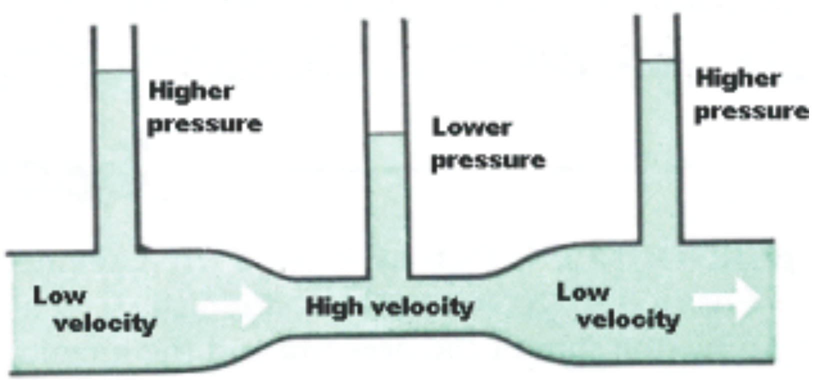
For traditional Biology majors

- The topics at left
- Reynolds number and Turbulence
  - Life at high and low Re
- Flight and Swimming
  - Drag, Lift, Thrust

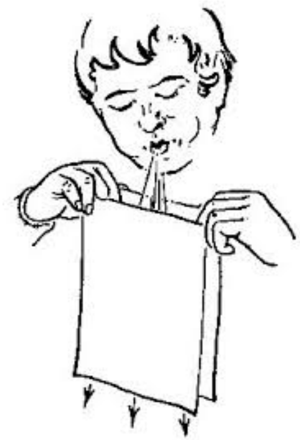
Unit on Dynamic Pressure

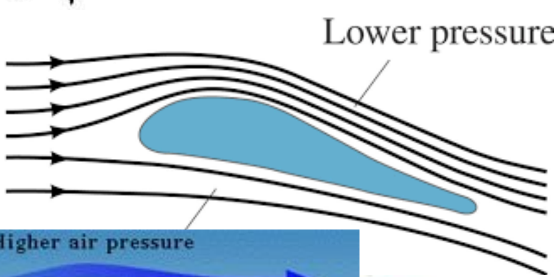
Old Habits

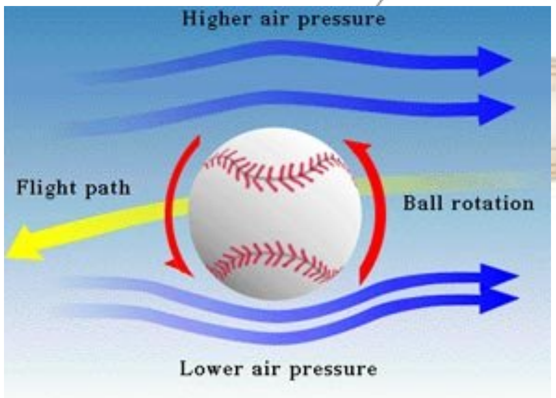


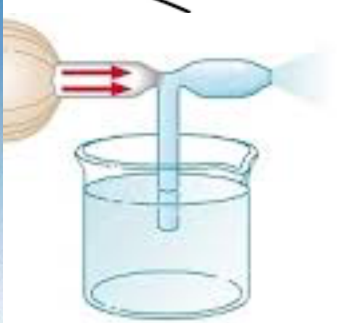


...and their applications









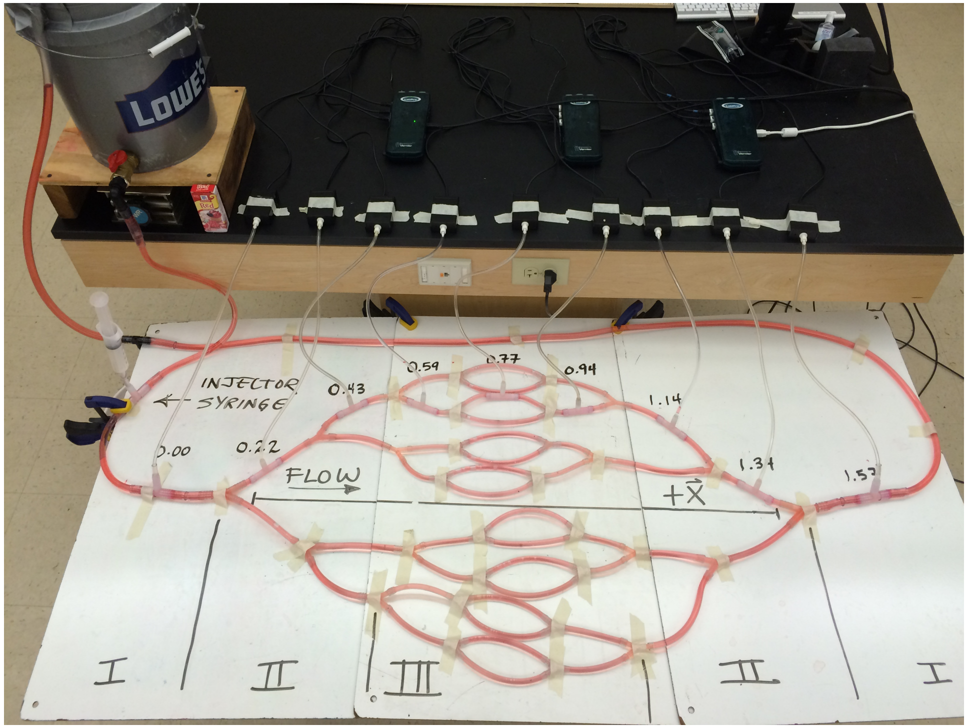
Maybe not?

Newton's 3rd Law, Coanda effect

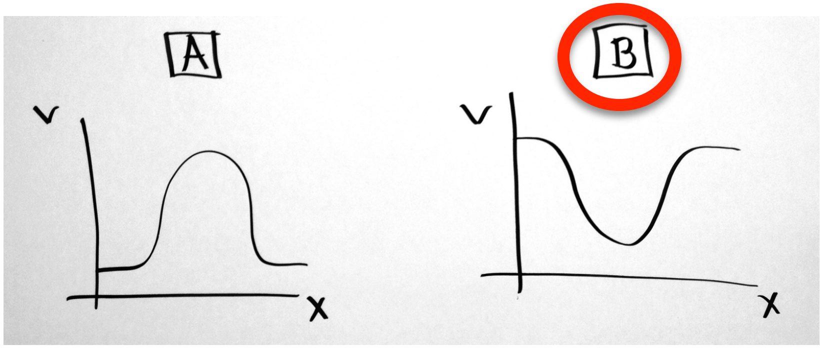
Entrainment, Vortices

Full system approach

Circulatory System Model

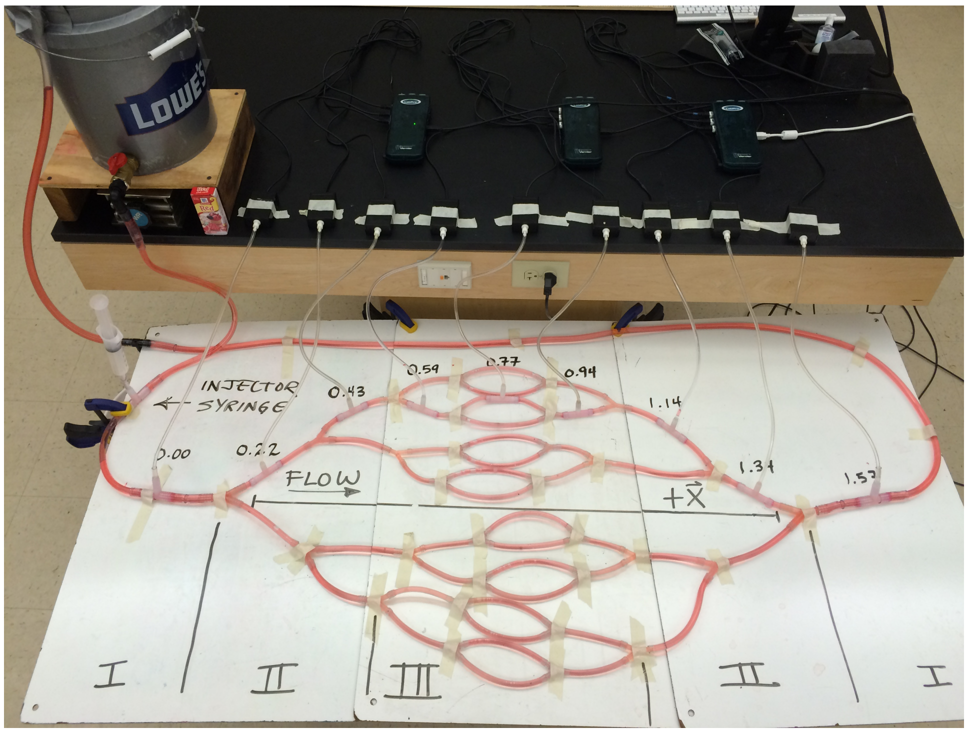


Predict the <u>speed</u> of the water as it passes through the apparatus.

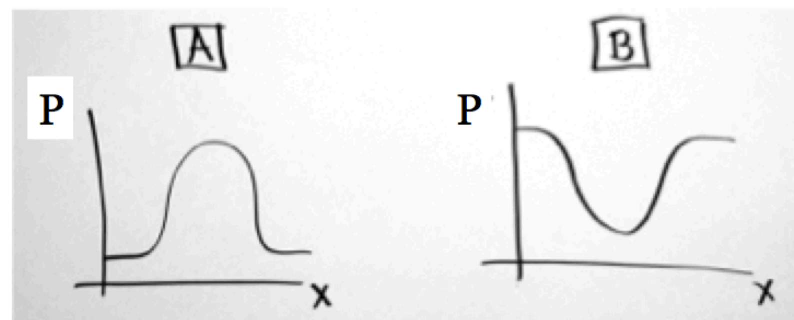


C. Other

Circulatory System Model

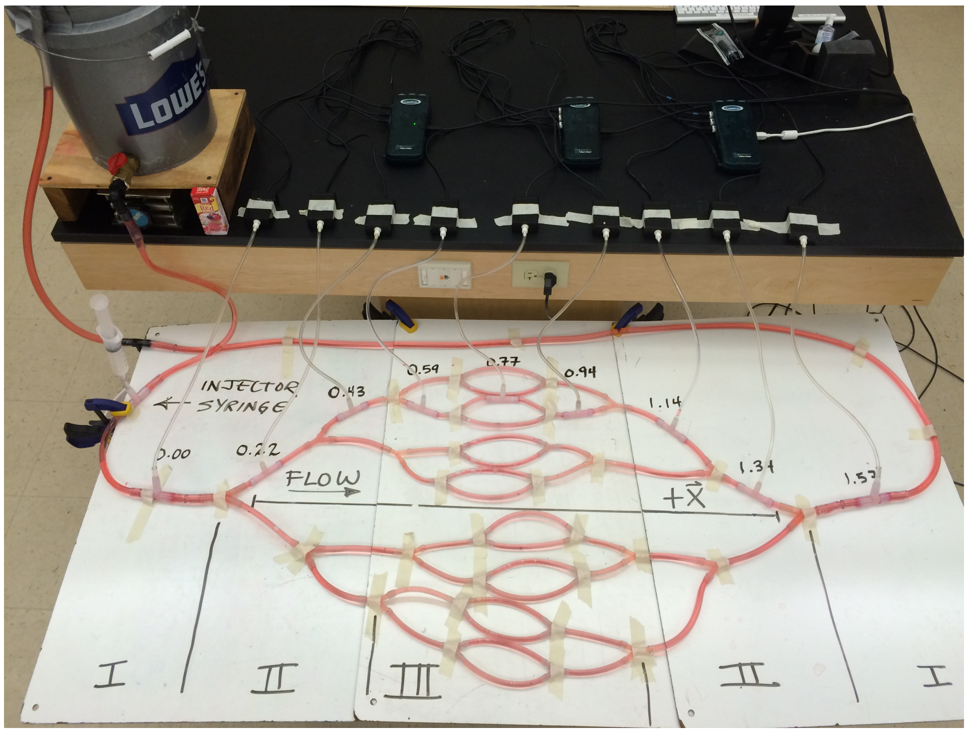


Predict the pressure of the water as it passes through the apparatus.

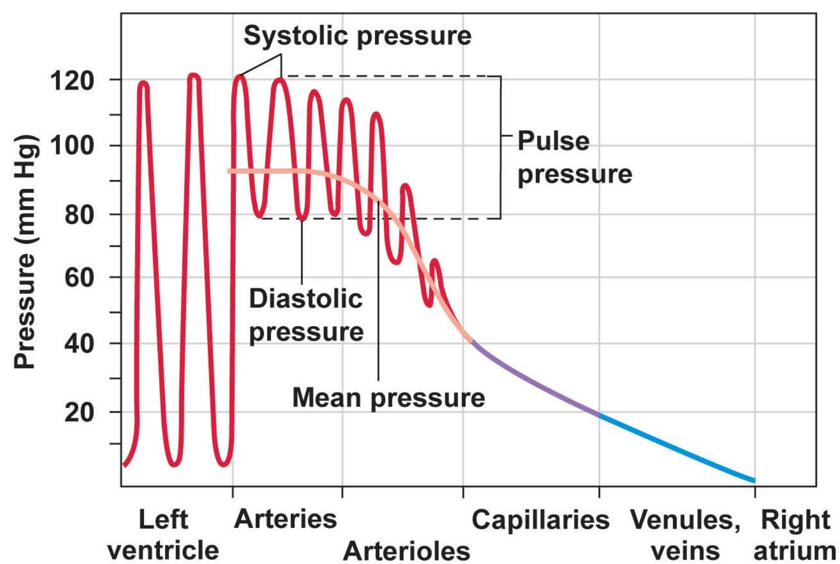


C. Other

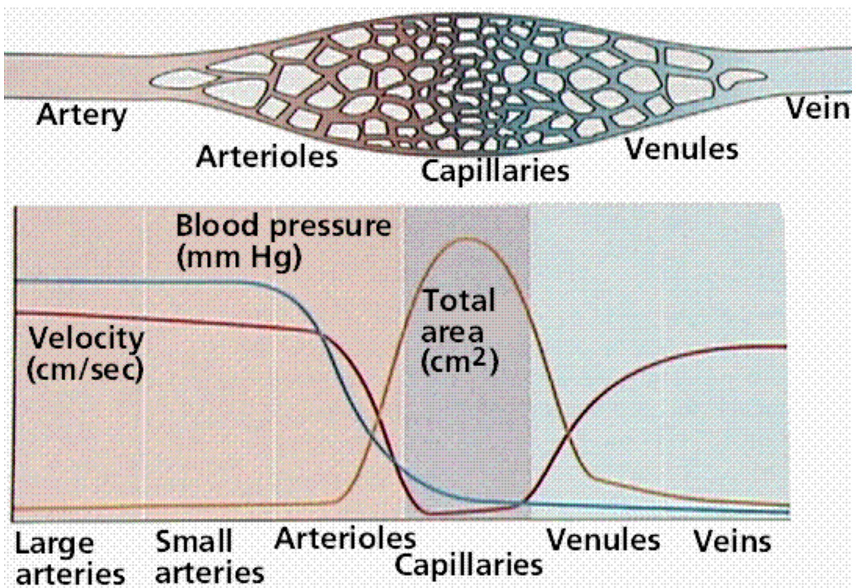
Circulatory System Model

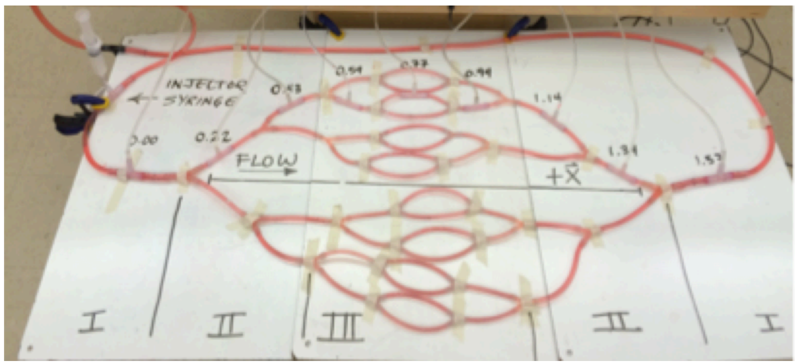


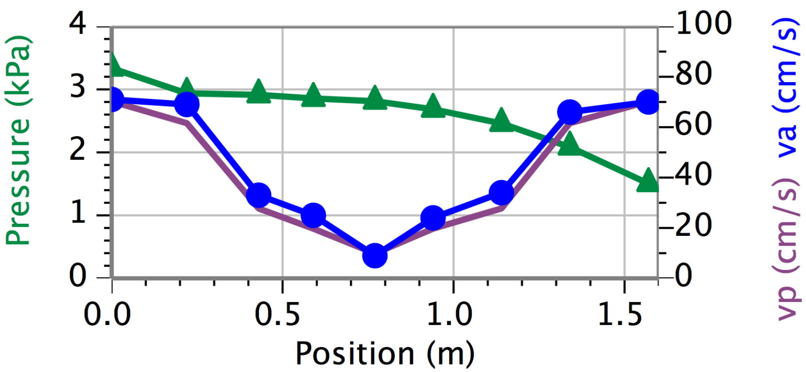
Predict the pressure of the water as it passes through the apparatus.



Human Body vs. Model Measurement







Mathematical Modeling

Laminar Flow:

$$\Delta P = -\rho g \Delta h - \frac{1}{2}\rho \Delta (v^2) - Q\frac{8\gamma L}{\pi r^4}$$

Bernoulli

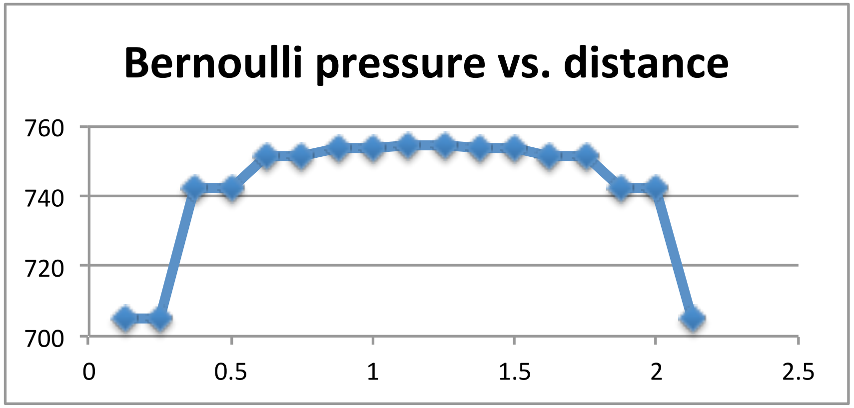
Poiseuille

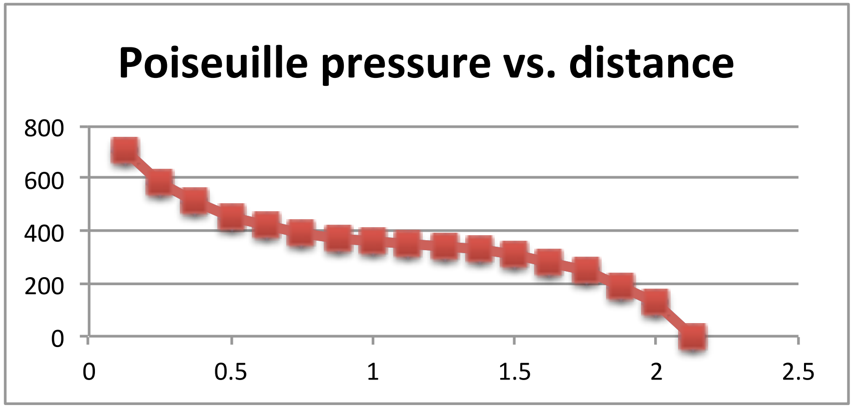
Bernoulli
or Poiseuille?

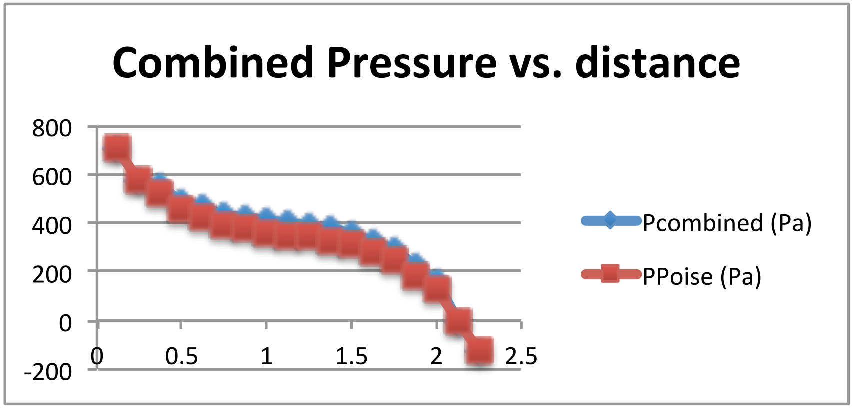
Laminar Conditions

- Tube radius = 0.32 cm
- Tube length = 12.5 cm
- Density = 1000 kg/m^3
- Viscosity = 0.004 Pa*s
- Starting pressure = 700 Pa
- Flow rate = 10 mL/s
- Reynold's # = 500

Bernoulli effect is negligible





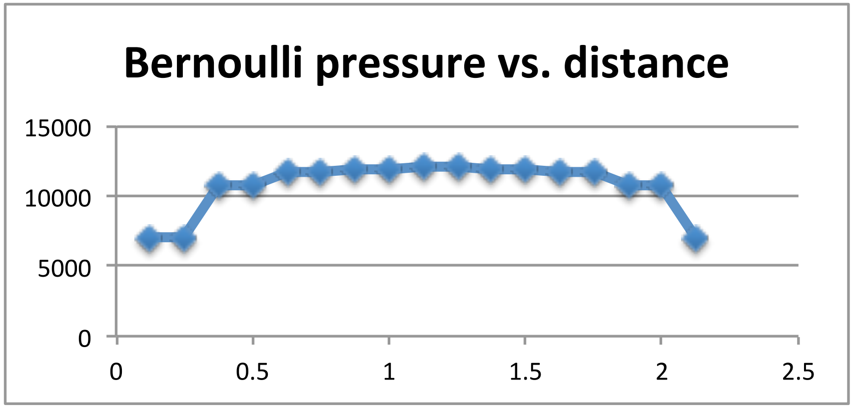


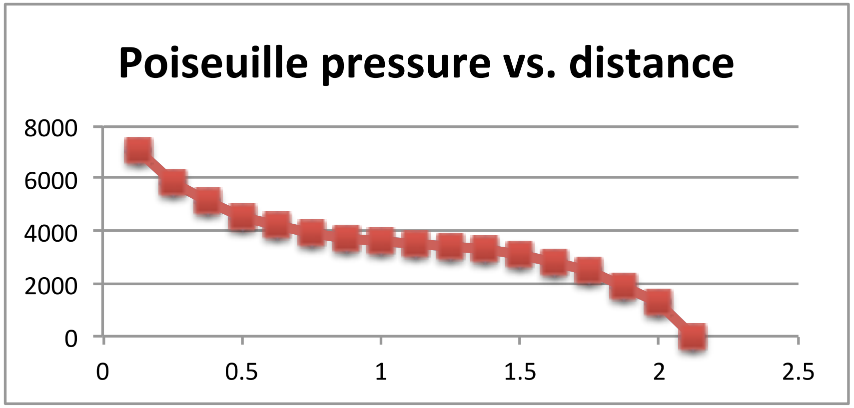
Bernoulli or Poiseuille?

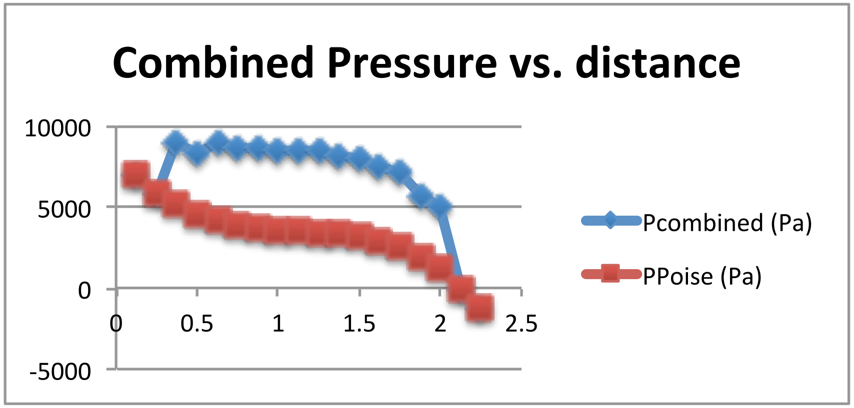
Turbulent Conditions

- Tube radius = 0.32 cm
- Tube length = 12.5 cm
- Density = 1000 kg/m^3
- Viscosity = 0.004 Pa*s
- Starting pressure = 7000 Pa
- Flow rate = 100 mL/s
- Reynold's # = 5000

Bernoulli effect seems measurable!







Mathematical Modeling

Turbulent Flow:

$$\Delta P = -\rho g \Delta h - \frac{1}{2}\rho\Delta(v^2) - \frac{f\rho L Q^2}{4\pi^2 r^5} - \frac{1}{2}K\rho\Delta(v^2)$$

Bernoulli — Major Loss — Minor Loss

Friction factor:

$$f = \frac{64}{\mathrm{Re}}$$

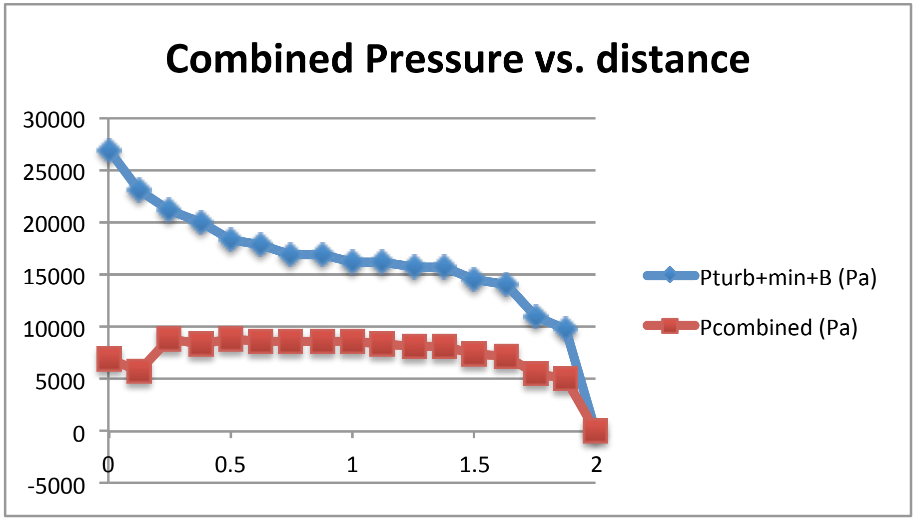
for laminar

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right)$$

for turbulent

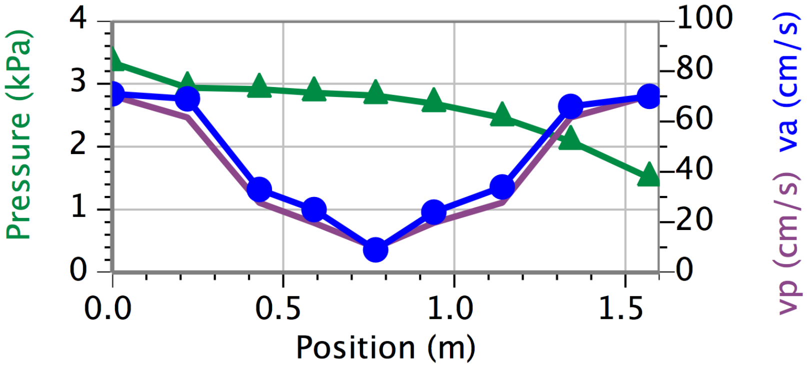
Hmm…

- The physics of turbulent flow
- Minor losses at junctions

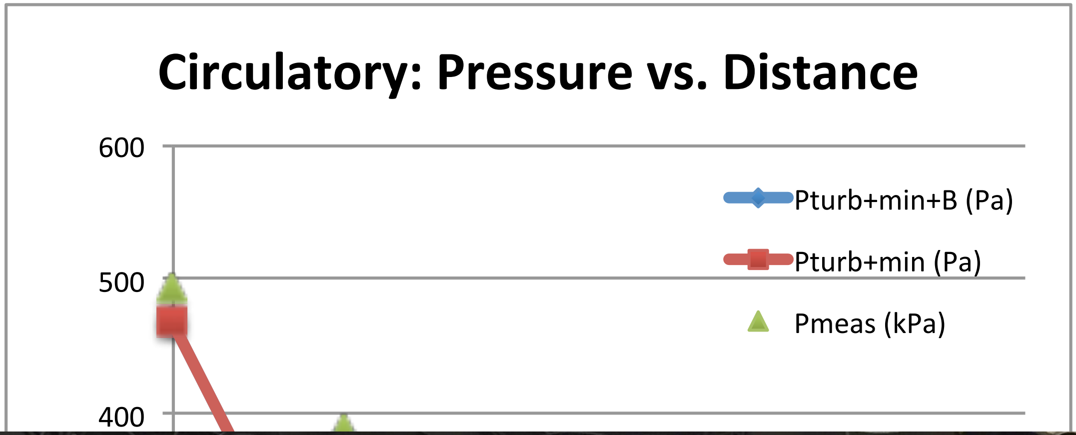


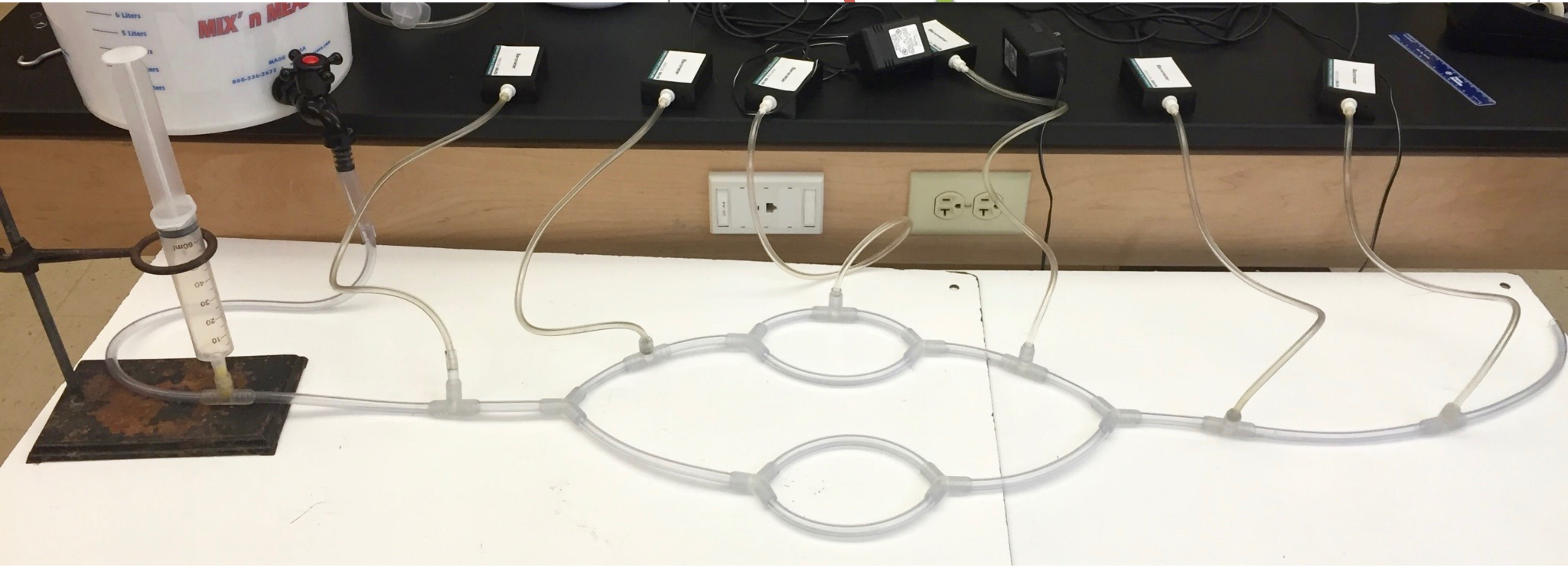
- This looks more like the Poiseuille pressure drop

- And the shape is reminiscent of the data

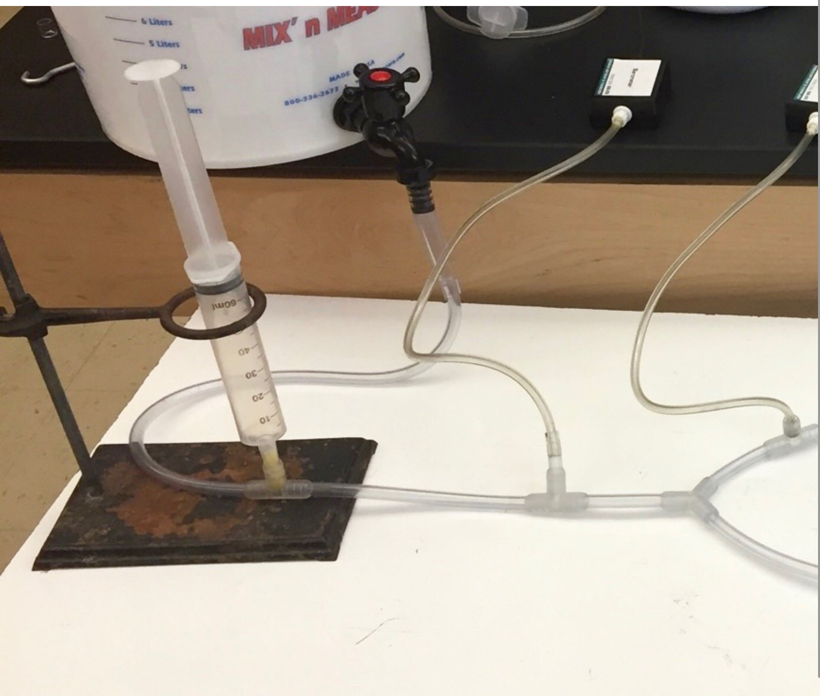


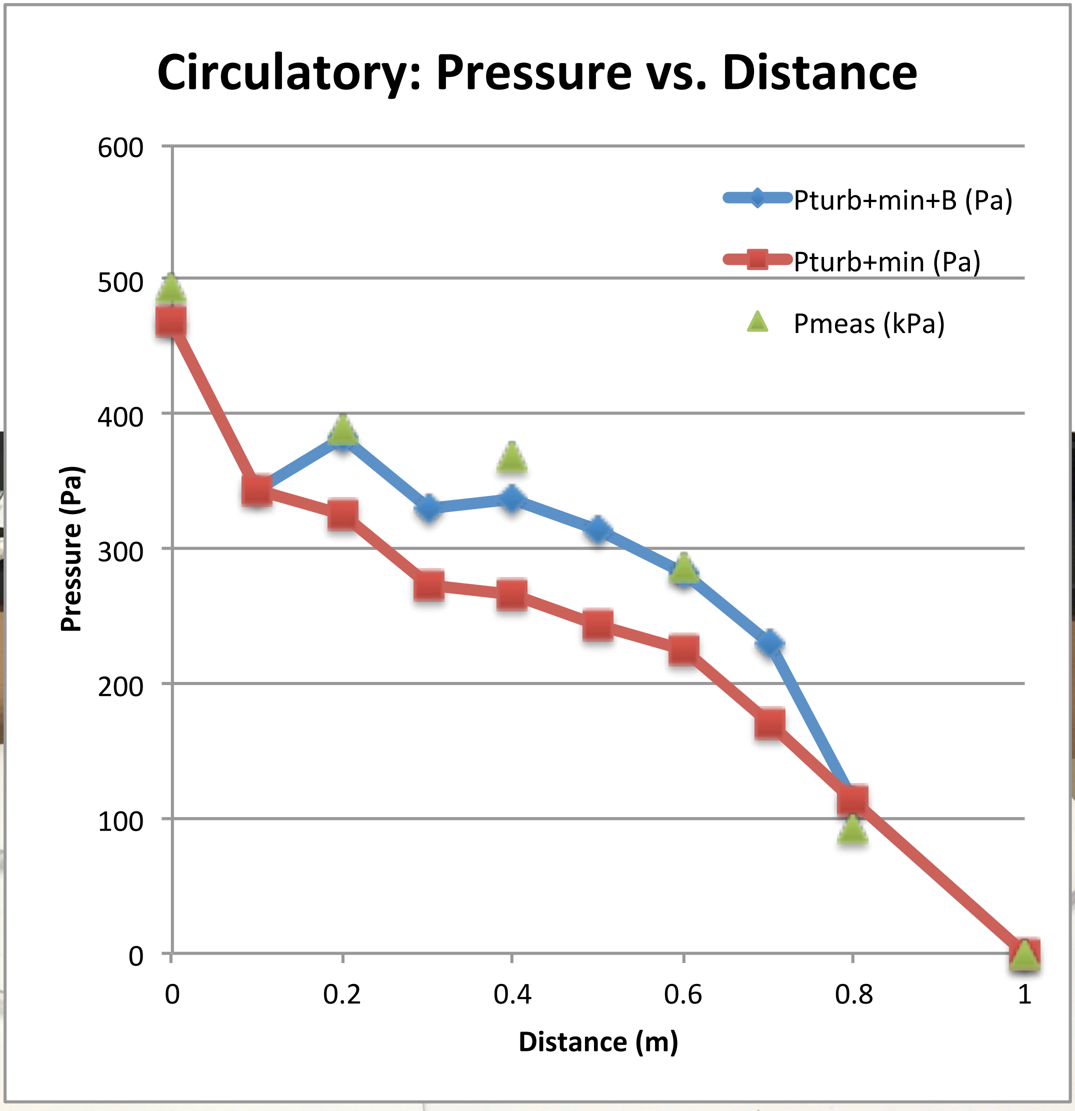
Modeling a smaller system…





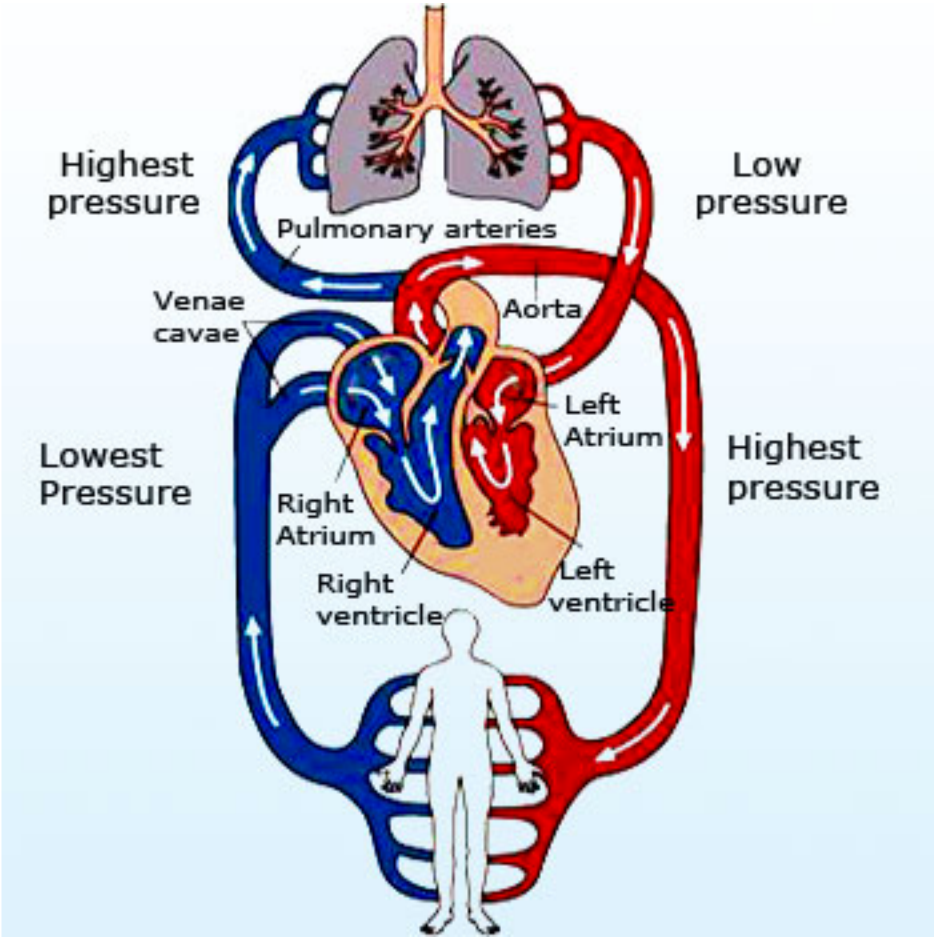
Modeling a smaller system…





The diagnosis

Flow in body is typically laminar.



<u>We need:</u>

- Equation of Continuity

$$A_1 v_1 = A_2 v_2$$

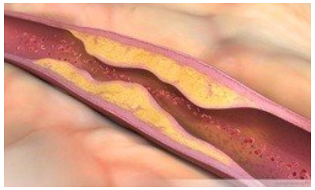
- Poiseuille's Law

$$\Delta P = QR$$

- Compliance

$$\Delta V = C \Delta P$$

- Diffusion (across capillaries)
- Bernoulli Principle + Laplace Law



For artherosclerosis

Teach Poiseuille First

This is a call for a Fluid Dynamics Paradigm Shift

The evidence in this talk supports the consideration of a Poiseuille first approach to teaching fluid dynamics. The growing emphasis on life science applications heightens the need to shift focus toward more realistic viscous and turbulent fluid properties.

AMERICAN JOURNAL of PHYSICS

Experiment illustrating Bernoulli's equation and Hagen–Poiseuille's law

J. Hellemans, P. Forrez, and R. De Wilde

Citation: American Journal of Physics **48**, 254 (1980); doi: 10.1119/1.12154
View online: http://dx.doi.org/10.1119/1.12154

In most handbooks Bernoulli's equation and Hagen–Poiseuille's law are treated separately. In this paper we present a simple and inexpensive experiment that introduces a combination of Bernoulli's equation and Hagen–Poiseuille's law, and with which students are made aware of the limitation of Bernoulli's equation.

AMERICAN JOURNAL of PHYSICS

On combining the Bernoulli and Poiseuille equation—A plea to authors of college physics texts

Costas Emmanuel Synolakis and Henry S. Badeer

Citation: American Journal of Physics **57**, 1013 (1989); doi: 10.1119/1.15812
View online: http://dx.doi.org/10.1119/1.15812

The Physics Teacher

The Bernoulli-Poiseuille equation

Henry S. Badeer and Costas E. Synolakis

Citation: The Physics Teacher **27**, 598 (1989); doi: 10.1119/1.2342887
View online: http://dx.doi.org/10.1119/1.2342887

"…we have noted a large number of students with the preconceived notion that the Bernoulli and Poiseuille equations are mutually exclusive."

"College physics texts present the Bernoulli equation as the most useful equation in fluid dynamics. Some texts also discuss the Poiseuille equation, which deals only with viscous flow. We suggest that a combination of the two equations is desirable."

Thanks for listening!

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