LECTURE 2: THE LOOK OF THE FLOW

EVERYTHING LAST TIME WAS TO EXPOSE YOU TO THE MACHINERY OF HOW FLUID EQUATION DERIVATIONS BEGIN. NOW LET'S LOOK AT PHENOMENON WE WANT TO DESCRIBE.

1) LAMINAR VS. TURBULENT FLOWS (REYNOLDS NUMBER)

2) ENTRANCE EFFECTS

3) THE BOUNDARY LAYER

4) BOUNDARY LAYER SEPERATION

5) SHOCK-WAVES

LATER IN COURSE...

EARLY EXPERIMENTS (1883) FOUND CLEAR QUALITATIVE DIFFERENCES IN FLOW BASED ON A NON-DIMENSIONAL NUMBER Re.

$$\text{Reynolds \#} = Re = \frac{\rho V D}{\mu} = \frac{VD}{\nu}$$

* WE ALL HAVE OUR OWN THOUGHTS ON THIS FAMOUS NUMBER

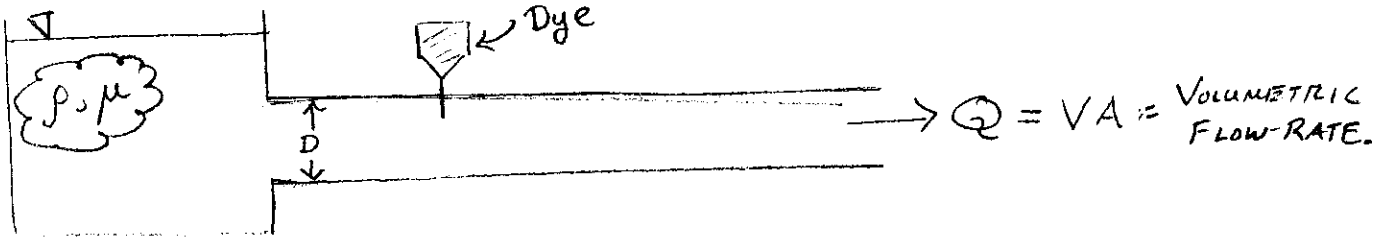
$$\text{Reynolds} = \frac{\text{Inertial Force}}{\text{Viscous Force}}$$

$$= \frac{\text{"Turbulence"}}{\text{"Laminar"}}$$

$$= \frac{\text{Viscous Time Scale}}{\text{Convective Time Scale}}$$

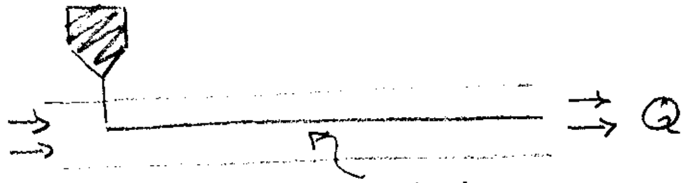
LECTURE 2: THE LOOK OF THE FLOW

Reynold's preformed these experiments . . .



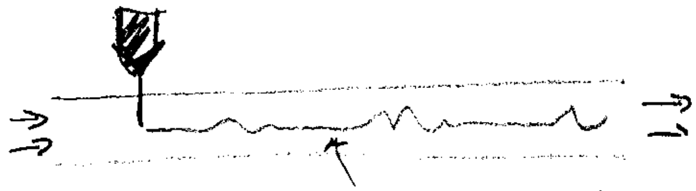
BY ADJUSTING THIS NON-DIMENCIONAL PARAMETER 3 DISTINCT FLOWS WERE OBSERVED.

Re < 2000



A distinct stream of dye flow undisturbed down pipe

Re ≈ 2000



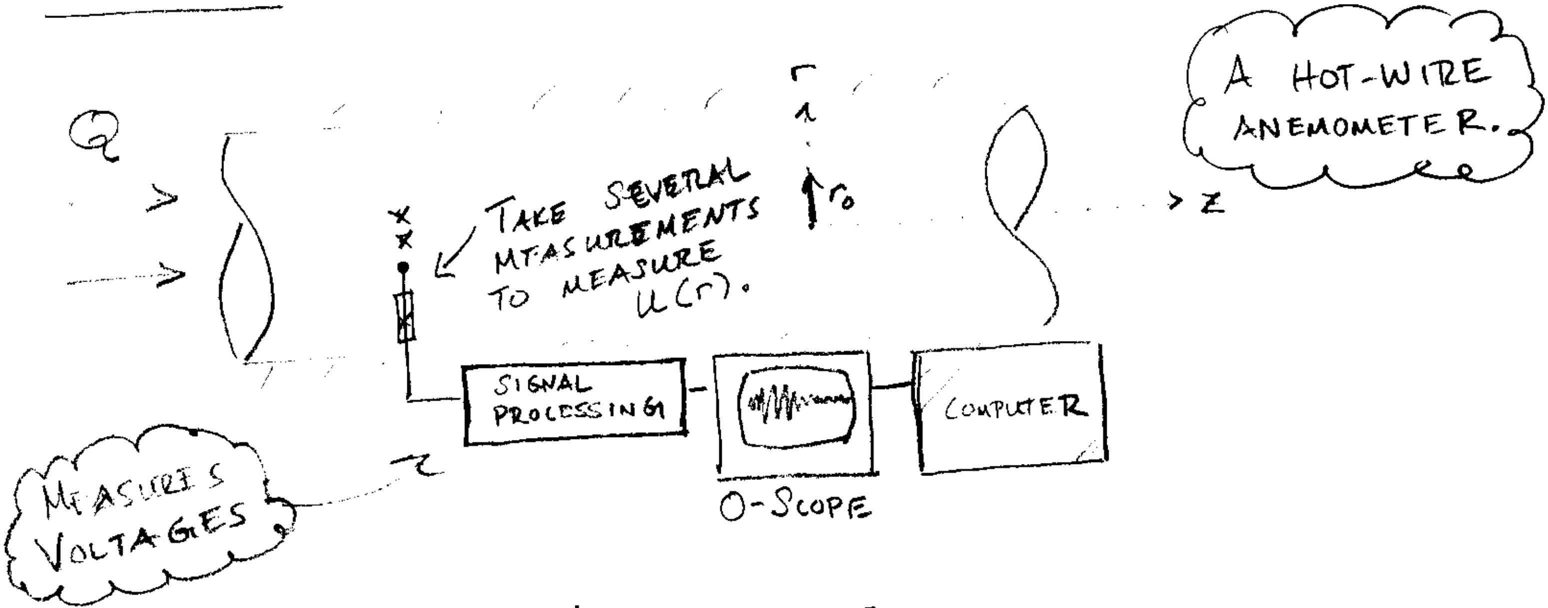
Some disturbances in the dye can be observed

Re > 2000

Dye becomes <u>mixed</u> into pipe flow.

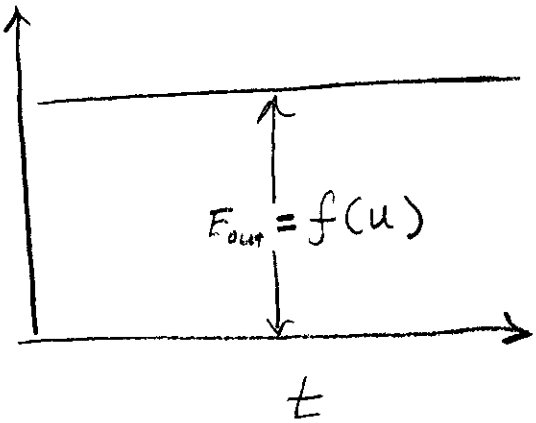
A STREAM OF DYE RELATES TO THAT STREAM FUNCTION THING WE LOOKED AT. PEOPLE ALSO CAN <u>MEASURE</u> DIRECTLY VELOCITY IN A PIPE AND ONE ALWAYS SEES THE SAME PLOTS

LECTURE 2 : THE LOOK OF THE FLOW



LAMINAR FLOW MEASUREMENT

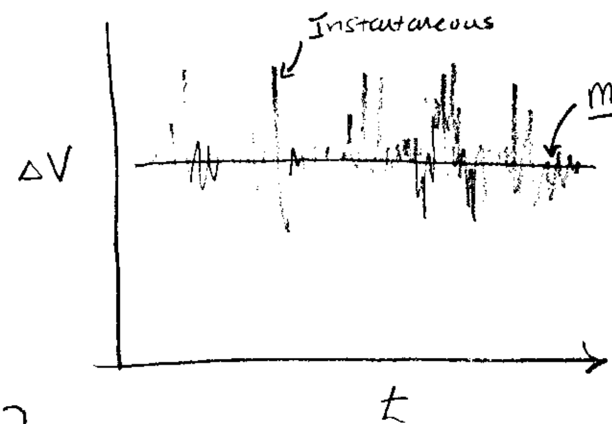
@ A GIVEN r_o



* CONSTANT READ-OUT FROM MEASUREMENT
* VELOCITY IS INFERED FROM EQUATING VOLTAGE ENERGY TO KINETIC
* TAKE SEVERAL MEASUREMENTS AT DIFFERENT r VALUES

TURBULENT FLOW MEASUREMENT

@ A GIVE r_o



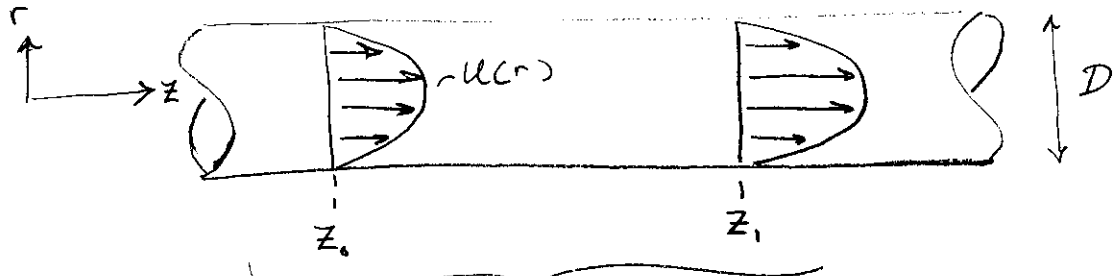
* JUST A MESS!
* A-LOT OF FLUCTUATIONS
* INSPIRES US TO CONSIDE

$$u = \overline{u} + u'$$

$$= \begin{Bmatrix} \text{mean} \\ \text{Velocity} \end{Bmatrix} + \begin{Bmatrix} \text{Instateous Velocity} \\ \text{FLUCTUATION} \end{Bmatrix}$$

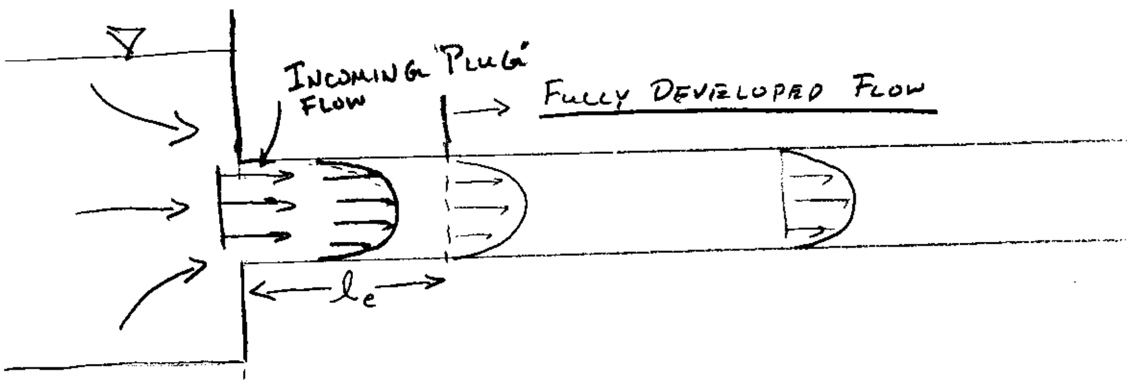
LECTURE 2 : THE LOOK OF THE FLOW

WHAT DOES "FULLY DEVELOPED" LOOK LIKE? MATHEMATICALLY IT MEANS $\frac{\partial}{\partial z} \equiv 0$.

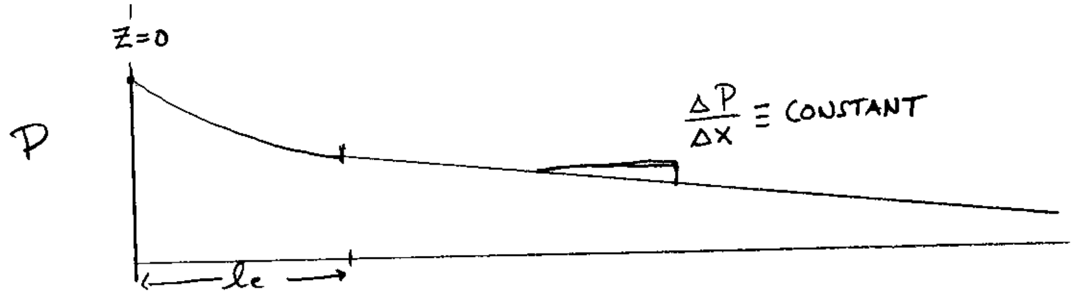


THERE IS NO DIFFERENCE IN THE VELOCITY PROFILE! $u \neq u(r,z)$. THE VELOCITY PROFILE IS NOT A FUNCTION OF THE STREAMWISE COORDINATE "z".

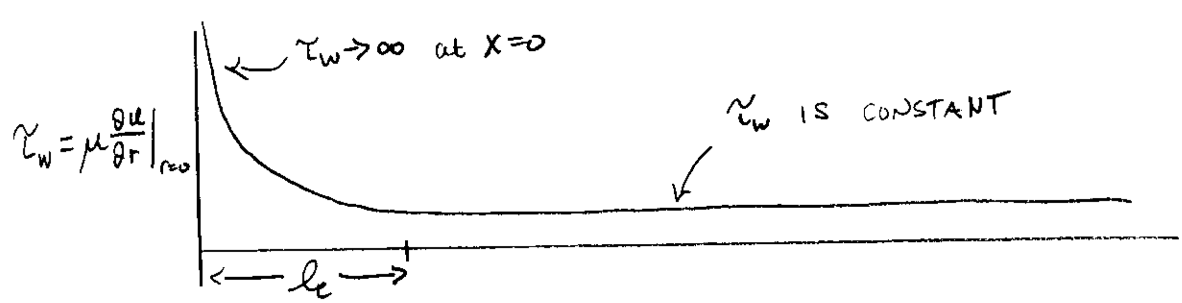
* PROBLEM IS THE ABOVE PICTURE HAS NO ENTRANCE. IN REALITY FLUID HAS ENTER A PIPE. IT COULD ALSO 'ENTER' AROUND A BEND, OR ENTER THRU A SCREEN.



VISUALLY



PRESSURE



SHEAR FORCE AT WALLS

LECTURE 2 : THE LOOK OF THE FLOW.

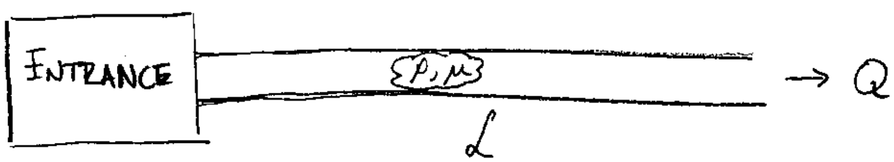
SO THERE IS SOME LENGTH l_e PAST WHICH MANY THINGS BECOME CONSTANT. THE FLOW BECOMES FULLY DEVELOPED. PEOPLE USED DIFFERENTIAL ANALYSIS TO DERIVE GREAT EQUATIONS ENGINEERS CAN CALCULATE TO TELL THEM WHEN FLOW IS FULLY DEVELOPED.

$Re < 2000$ $\qquad \dfrac{l_e}{D} \approx 0.06\, Re$ $\qquad$ (laminar flow)

$Re > 2000$ $\qquad \dfrac{l_e}{D} \approx 4.4\, Re^{1/6}$ $\qquad$ (turbulent flow)

$Re = \dfrac{\rho V D}{\mu}$ or $\dfrac{VD}{\vartheta}$. $D \equiv$ DIAMETER OF PIPE.

WHO CARES!? WELL THESE RELATION TELL ENGINEERS WHAT MODEL TO USE FOR THEIR PIPE PROBLEMS



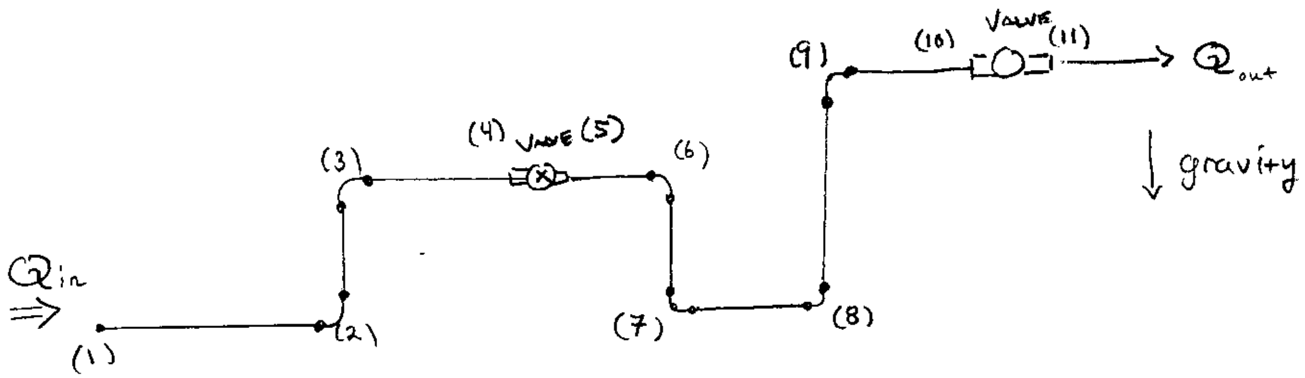
i) IF $l_e \ll \mathcal{L}$ THEN WE CAN MODEL THE PIPE AS FULLY DEVELOPED THRU-OUT THE ENTIRE PIPE.

ii) IF $l_e > \mathcal{L}$ THEN FLUID WILL NOT BE-ABLE TO BECOME FULLY DEVELOPED, VERY HIGH WALL STRESS

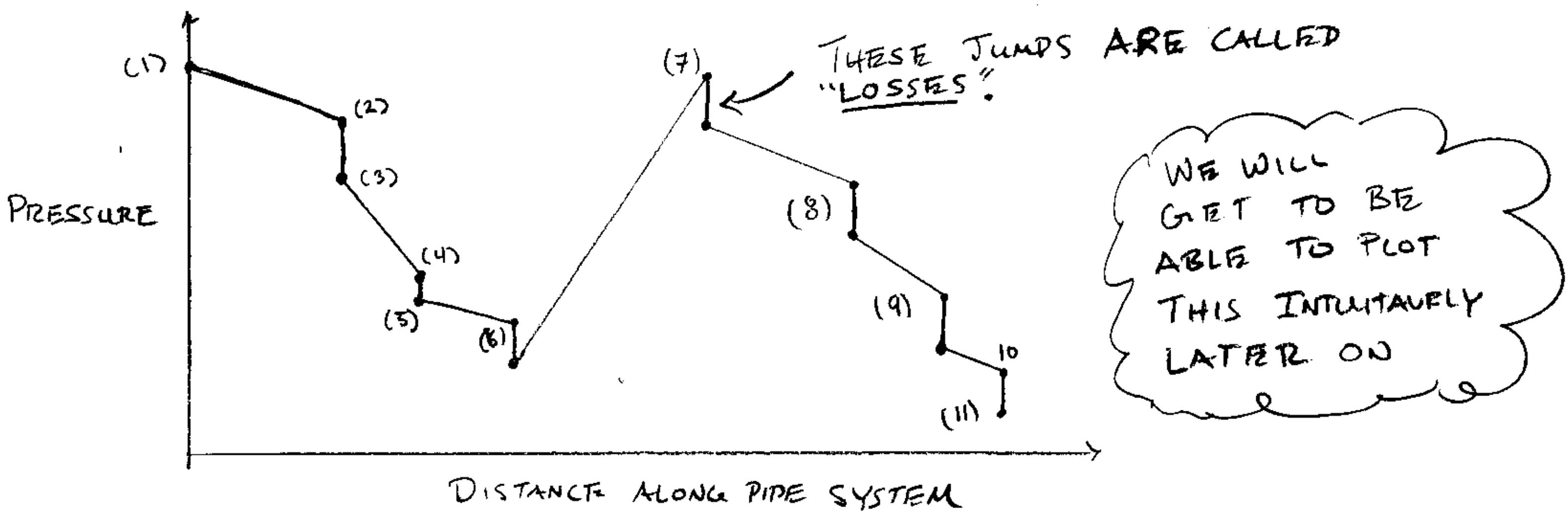
iii) IF $l_e \lesssim \mathcal{L}$ OR ENTRANCE LENGTH IS LESS, BUT NOT LESS BY A LOT, THE BOTH REGIONS NEED TO BE MODELED

LECTURE 2 : THE LOOK OF THE FLOW

IT IS PRETTY EASY TO MEASURE PRESSURES IN PIPE FLOWS AND MAKE OUR OWN PLOTS (NO MATH). SO IF WE HAVE A BUNCH OF PIPE CONNECTED WITH ELBOWS & VALVES LIKE ...



WE MEASURE EACH NODE (K) AND PLOT PRESSURES. WHAT DOES IT LOOK LIKE IF WE DO THIS?



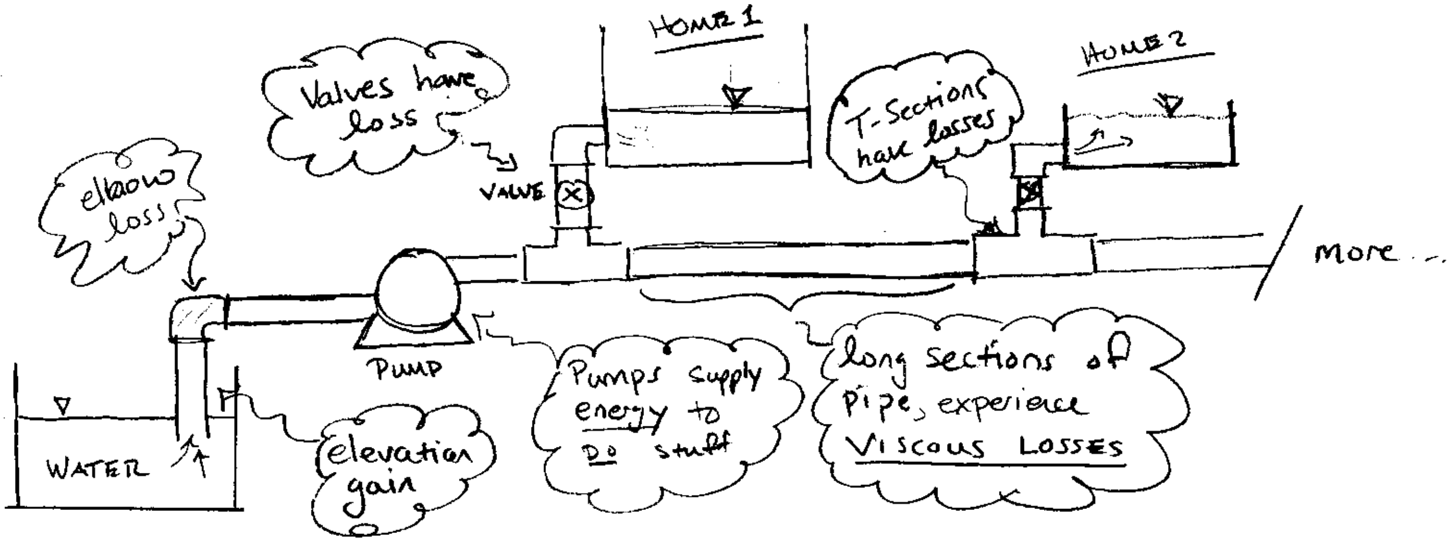
EVERY TIME OUR FLUID HAS TO PASS THRU ONE OF THESE COMPONENENTS WE OBSERVE DISCONTINUITY IN OUR PLOT.

1) WE WOULD LIKE TO ESTIMATE THESE JUMPS WITHOUT RUNNING AN EXPERIMENT EVERY TIME

2) WE WOULD LIKE TO KNOW WHY THERE ARE THESE SHARP DROPS

THESE EFFECTS ARE WHAT WE SEEK TO QUANTIFY BY LOOKING AT THE MATH, THE PHYSICS, ETC.

LET'S TRY TO IMAGINE A "WHITE BOARD" PROBLEM. SOME MEETING WHERE A WHITE BOARD IS PRESENT AND A BUNCH OF ENGINEERS ALL BRAIN-STORMING TO SOLVE A PROBLEM.



Q: WHAT KIND OF PUMP(S) DO WE NEED TO GET WATER TO OHSU ON TOP OF THE HILL. HOW POWERFUL DOES IT NEED TO BE? DO WE NEED MULTIPLE?

THIS IS A HARD PROBLEM, BUT WE WILL DEVELOP TOOLS (CALCULATIONS) THAT WILL HELP US ACCOUNT FOR ALL THE LOSSES OF THE SYSTEM. HERE'S HOW...

1) CONSIDER LAMINAR FLOW IN A STRAIGHT PIPE

2) FORMULATE TURBULENT PIPE FLOW INSPIRED BY LAMINAR SOLUTIONS

3) USE SOLUTIONS TO CALCULATE ENERGY REQUIREMENTS OF LONG SECTIONS OF PIPE.

4) USE SAME REASONING TO ESTIMATE COMPONENT LOSSES (GIVEN AN EXPERIMENTAL PARAMETER)

5) FORMULATE HOW ONE COULD CALCULATE REQUIREMENTS (PUMP), (PIPE DIMENSION), (FLUID), ETC ...