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MET 330 Fluid Mechanics
Dr. Orlando Ayala
Spring 2022
Test 2

Take home – Due Tuesday March 22nd, 2022, before midnight.

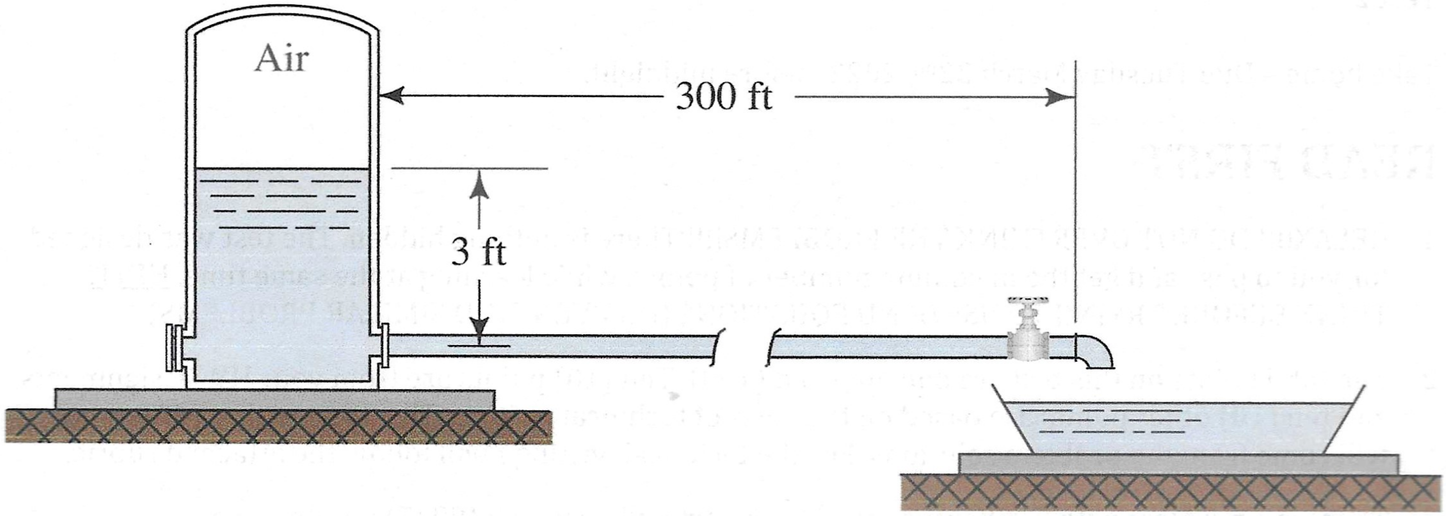
READ FIRST

1. RELAX!!!! DO NOT OVERTHINK THE PROBLEMS!!!! There is nothing hidden. The test was designed for you to pass and get the maximum number of points, while learning at the same time. HINT: THINK BEFORE TRYING TO USE/FIND EQUATIONS (OR EVEN FIND SIMILAR PROBLEMS)
2. The total points on this test are one hundred (100). Ten (10) points are from your HW assignments, and ten (10) other points are based on the basis of technical writing. The other eighty (80) points will come from the problem solutions. For the technical writing I will follow the attached rubric.
3. There is 1 problem with 7 different parts. Each part will be worth (80/7) points.
4. What you turn in should be only your own work. You cannot discuss the exam with anyone, except me. Call me, skype me, text me, email me, come to my office, if you have any question.
5. I do not read minds. You should be explicit and organized in your answers. Use drawings/figures. If you make a mistake, do not erase it. Rather use that opportunity to explain why you think it is a mistake and show the way to correct the problem.
6. You have to turn in your test ON TIME and ONLY through BLACKBOARD. You must submit only one file and it has to be a pdf file. For the ePortfolio (which is optional) you are supposed to upload this artifact to your Google drive. I will provide more instructions later.
7. Do not start at the last minute so you can handle anything that could happen. Late tests will not be accepted. Test submitted through email will not be accepted either.
8. Cheating is completely wrong. The ODU Student Honor Pledge reads: "I pledge to support the honor system of Old Dominion University. I will refrain from any form of academic dishonesty or deception, such as cheating or plagiarism." By attending Old Dominion University you have accepted the responsibility to abide by this code. This is an institutional policy approved by the Board of Visitors. It is important to remind you the following part of the Honor Code:

   IX. PROHIBITED CONDUCT
   A. Academic Integrity violations, including:
   1. *Cheating*: Using unauthorized assistance, materials, study aids, or other information in any academic exercise (Examples of cheating include, but are not limited to, the following: using unapproved resources or assistance to complete an assignment, paper, project, quiz or exam; collaborating in violation of a faculty member's instructions; and submitting the same, or substantially the same, paper to more than one course for academic credit without first obtaining the approval of faculty).

With that said, you are NOT authorized to use any online source of any type, unless is ODU related.

A company hired an engineer to design the system below. However, the engineer quitted and now you are hired to finish the work. The system is supposed to deliver 60 °F water at a rate of 75 gpm from a pressurized storage tank to a trapezoidal open channel through 300 ft of 1 ½ in Schedule 40 steel pipe as shown in the figure. The modulus of elasticity of steel is 200 GPa. The purpose of the open channel is to carry hickory wood logs downstream (they will float). The density of hickory wood is 830 kg/m^3



The company would like you to complete the following tasks.

open channel flow

a. What is the water depth (y) in the open channel? The angle of the lateral walls is 60°. The width at the top of the water (T) is T=2.309y (see table 14.3 in the book). The channel slope is 0.1 percent and is made of unfinished concrete.

Motion of forces due to ~~static~~ fluids

b. The pipe needs to be supported. Your civil engineer colleague requires to know the relevant forces for the support design. Calculate the total horizontal and vertical forces in the whole system pipe-elbow.

Buoyancy + Stability

c. What is the largest hickory wood log the open channel can carry? The log should barely float. The log has a square cross section. Is it stable? Prove the stability answer using the equations.

d. Your client also proposes to use a flow nozzle to measure the flow. For a nozzle diameter to pipe diameter ratio of 0.5, what is the pressure drop across the nozzle? Instrumentation

e. If the valve in the pipe closest suddenly, what is the pressure increment after the sudden closing? Is there any change of cavitation in your system? Why? water hammer/ Cavitation

f. Assuming a log with half of the size of the largest log that can be carried in channel (the one computed in part c), what is the largest drag force it would experience if it got stuck at the bottom of the channel? Make any reasonable assumption. drag + Lift

g. Compute the force acting upon the blind flange at the left-hand-side of the tank. The diameter of the blind flange is the same as the pipe diameter. Where is the force location?

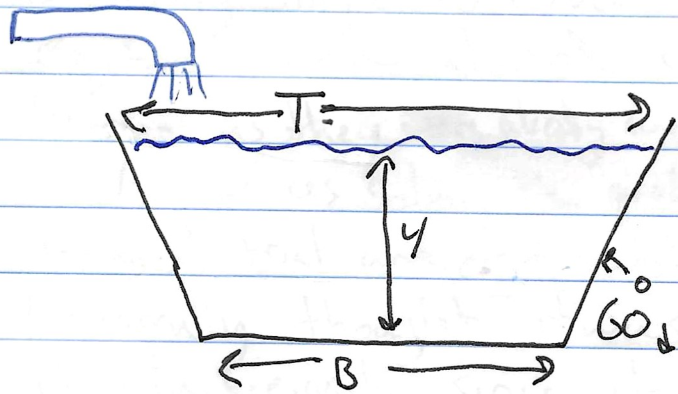
~~Impulse theorem~~ static fluids

Erich Schimpf
Test 1

(a) OPEN CHANNEL FLOW

* I will use Moon Landing Units for this

Find water depth (y)



Knowns

$T = 2.309y$

$B = 1.55y$

Slope $= .1\% = .001 = S$

$Q = 75\ gpm = .1671\ ft^3/s$

$n = .017$

$A = 1.73y^2$

$WP = 3.46y$

$R = y/2$

Open Channel flow

$$Q = \frac{1.49}{n} A S^{\frac{1}{2}} R^{\frac{2}{3}}$$

Rearanged to have all Knowns on one side

$$AR^{2/3} = \frac{nQ}{1.49S^{1/2}}$$ Plug in variables

$$1.73y^2\left(\frac{y}{2}\right)^{2/3} = \frac{(.017)\cdot(.1671)}{1.49\,(.001)^{1/2}}$$

$= .06028$

$3\left(\frac{1.73y^2\ y^2}{y}\right) = .00072\cdot y = \sqrt[8]{0.00016} = .33\ ft$

~~$5.177y^8 = \sqrt[8]{.000556} = .39\ ft = y$~~

Part ⓐ analysis

This part was a fairly straight forward example od an open channel flow problem. The Table provided, 14.3, made it exceedingly simple to reduce the variables in the equation, and allowed you to simply plug them in as they were already functions of y (height)

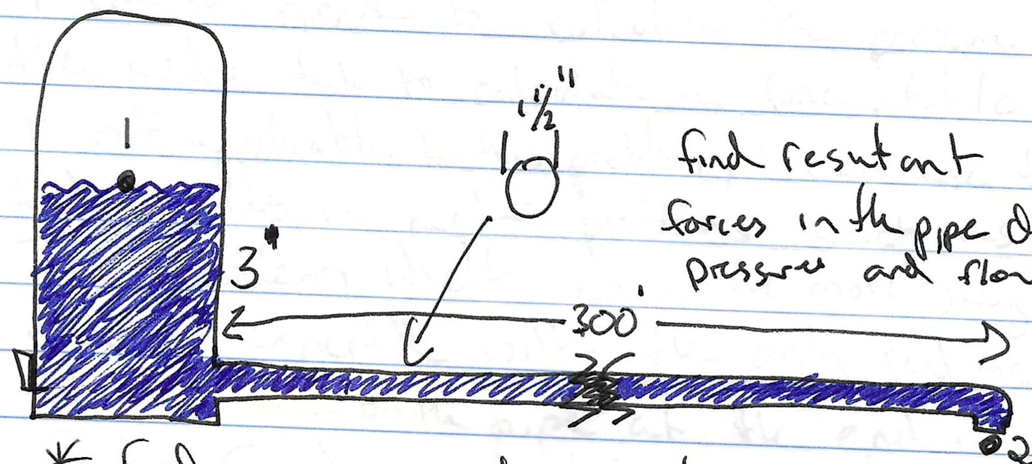
As far as solving the problem, the example uses a trial and error substitution to find h. I personally thought it was easier to solve it algebreically since it was already made so straightforward, but a method similar to what was shown to us in class the 17th using excell to generate the correct answer could also be used if table 14.3 was not available, or the shape of the channel was not listed.

~~* I also noticed a discrepancy between the open channels lecture and example, when presenting the equation for flow rate, the lecture lists the first term as $\left(\frac{1.0}{n}\right)$ while the example lists $\left(\frac{1.49}{n}\right)$. I did go back and ammend this as both the lecture and book state $\left(\frac{1.0}{n}\right)$, so I used that value.~~

Dis Regard

Part B

forces due to the motion of fluids



find resultant forces in the pipe due to pressure and flow

* find pressure of air at the top of the tank

$Q = A \cdot V \therefore V = \dfrac{.1671\,ft^3/s}{\left(\frac{1.5}{12}ft\right)^2 \cdot \frac{\pi}{4}} = V = 13.62\,ft/s$ @ pipe

$\cancel{h_A} + \dfrac{P_1}{\gamma} + \cancel{\dfrac{V_1^2}{2g}} + z_1 = \cancel{\dfrac{P_2}{\gamma}} + \dfrac{V_2^2}{2g} + \cancel{z_2} + \cancel{h_R} + h_L$

find P_1 ; $z_1 = 3$ $\quad V_2 = 13.62$, $h_L = K\left(\dfrac{V^2}{2g}\right)$ $\quad K = L/D \cdot f_T$ (P241)

$f_T = 0.02 \quad K = 300 \cdot .02 = 6 \cdot \dfrac{13.62^2}{2 \cdot 32.2} = 17.28 = h_L$

$\therefore$

$\dfrac{P_1}{62.4} + 3 = \dfrac{13.62^2}{2(32.2)} + 17.28 = \boxed{P_1 = 1070.8\,lb/ft^3}$

$F_x = R_x \qquad F_x = \rho Q\left(V_{2_x} - V_{1_x}\right)$

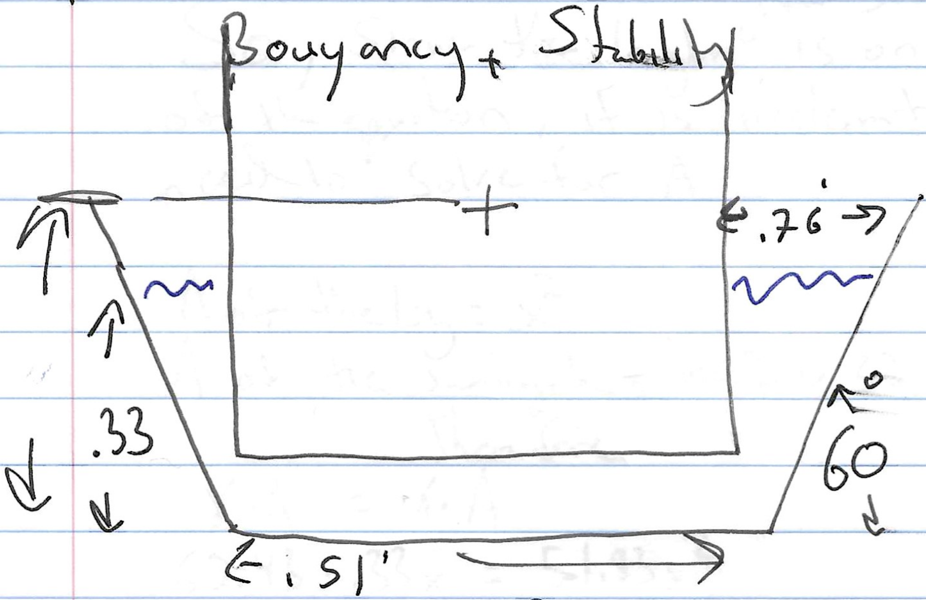
$F_x = F_y$ since $90°$

$F_x = 1.94 \cdot .1671 \cdot 13.62 = \boxed{4.4166}$

$F_y = 4.4166$

For part B I incorrectly assumed that I would need to need to calculate the pressure inside the water tank to calculate the force. While this is not applicable to this problem, I can use the found values in further problems such as g. The problem itself was far more straightforward than I expected with the only real forces being at the bend of the pipe at the end. I also spend some time second guessing my approach as the Modulus of elasticity is given and I thought that might have something to do with this problem but I now realize it is likely going to be used in problem g.

Part C



water is .33' deep

$\gamma_{log} = 51.83\ lb/ft^3 \cdot 32.2 =$

$\gamma_{log} = 1668.93\ lb/ft^3$

$\gamma_{water} = 62.43\ lb/ft^3$

$\rho_{log} = 51.82\ lb/ft^3$

$F_b = \gamma_{fluid} \cdot V_{d\,fluid}$

Determine Volume of the log

$W_{log} < F_b$

$W_{log} = V \cdot 1668.93\ lbf/ft^3$

508.57

$V \cdot ~~1668.93~~\ lbf/ft^3 < 62.43\ lbf/ft^3$

So, since the base of the channel is ≈6", any size more than that would hit the sides and not float. Therefore, the MAX cross sectional area is 6" x 6"

SO $V = .5 \cdot .5 \cdot x$

$V_d = .33 \cdot .5 \cdot x$

~~$.5' \cdot .5' \cdot x' \cdot 1668.93\ lbf/ft^3 < 62.43 \cdot .33' \cdot .5' \cdot x$~~

~~$417.2325x < 10.3x$~~

~~$40.5x < x$~~

So, Since the length of the log is on both sides of the equation, it is irrelevant, you only need to solve for A

A of the log $= x^2$

A of the submerged $=$ ~~x~~ $.33x$

Therefore

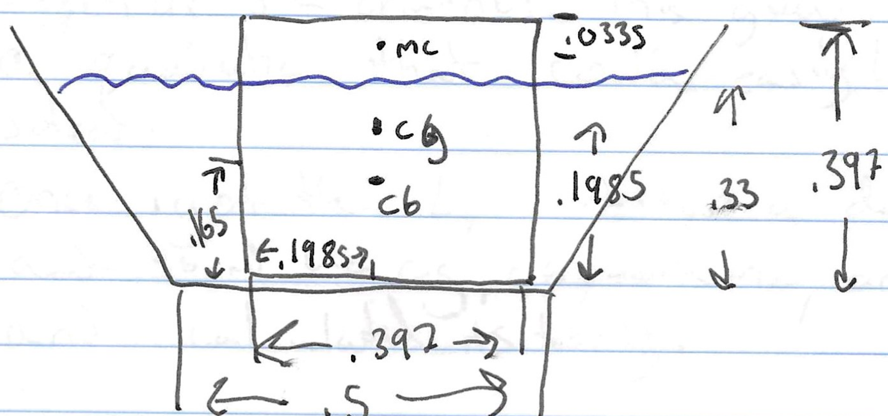
$\gamma \cdot A = \gamma \cdot A$

$62.43 \cdot .33x = 51.83x^2$

$20.60x = 51.83x^2$

$x \leq .397'$

Optimally the logs should be less than or equal to $.397' \times .397'$



MB = .1985

for stability, the following must be true

$L_{cb} + MB > L_{cg}$

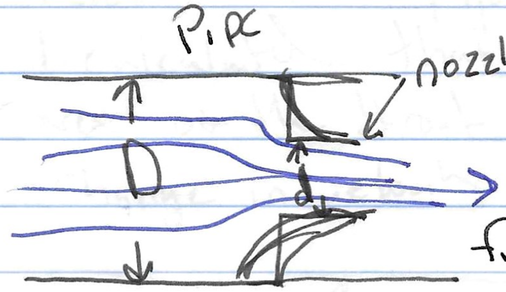
$\therefore$

$.165 + .1985 > .1985$ ✓

Floating body is Stable

Originally in this question, I was very confused. I incorrecty assumed the cross sectional area and thought I was solving for length, but realized that I would get $ax = 6x$ equations.
I then realized that the length is entirely irrelevant. the length is the same for the volume of the body and the volume displaced by the body, so I ignored it.
I then stated that the crosssectional area, A, is equal to L^2, while the area displaced is equal to L times the depth of the channel. this gave me a quadratic that could easily be solved.
Once i got the L, I drew a diagram and found the cg, cb, ~~and~~ mc, and MB, and calculated its stability.

Part d



ratio of .5

D = 1.5" or 0.125'

d = .75" 0.0625'

find pressure drop across nozzle

ΔP

$$v_1 = C\sqrt{\frac{2g(p_1 - p_2)/\gamma}{(A_1/A_2)^2 - 1}}$$

$Q = A_1V_1 = A_2V_2$ — V_2, not V_1 — $A_d = .0625^2 \cdot \frac{\pi}{4} = .00307'$

$.1671 \, ft^3/s = .00307 ft^2 \cdot V_1$ $\boxed{V_1 = 54.42}$

$C = 0.9975 - 6.53\sqrt{\beta / N_R}$ $\beta = \frac{d}{D} = .5$ $N_R = \frac{vD}{\nu}$

$N_R = \frac{54.42 \cdot .125}{1.21 \times 10^{-5}} = 562190 = 5.6 \times 10^5 \therefore \boxed{C = 0.9913}$

$$54.42 = .99 \cdot \sqrt{\frac{2(32.2)(\Delta P)/62.4}{\left(\frac{.012272}{.00307}\right)^2 - 1}}$$

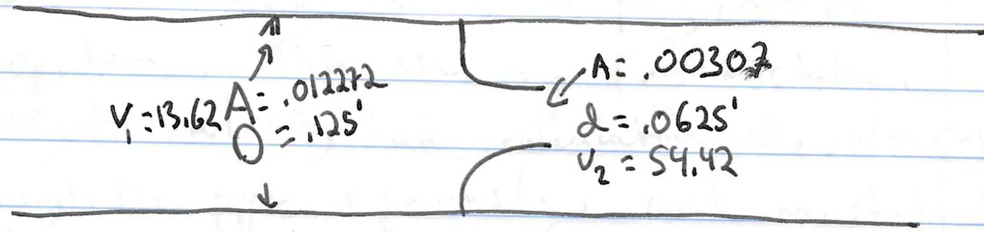
$$\frac{3021.66\,(14.98)(62.4)}{(32.2 \cdot 2)}$$

Attempt #2, Part d

Velocity in the pipe is 13.62, NOT 54

I calculated that velocity using the area of the throat, which makes sense

Change in velocity goes from 13.62 to 54.42



$V_1 = 13.62$ $\quad A_1 = .012272$

~~C = .99~~ $\quad A_2 = .00307$ $\quad N_R = 140702 = 1.4 \times 10^5$

$\gamma = 62.4$ $\quad C = .9851$

$$13.62 = .99\sqrt{\frac{2 \cdot 32.2 \cdot (\Delta P)/62.4}{\left(\frac{.012272}{.00307}\right)^2 - 1}}, \quad \Delta P = 2747 \text{ lb/ft}^2$$

* using $P_1 = 1258$ from part g

Pressure drop across the nozzle is ~~P_2~~

~~-1489.07~~ with wrong C

With proper C, -1515.9 lb/ft²

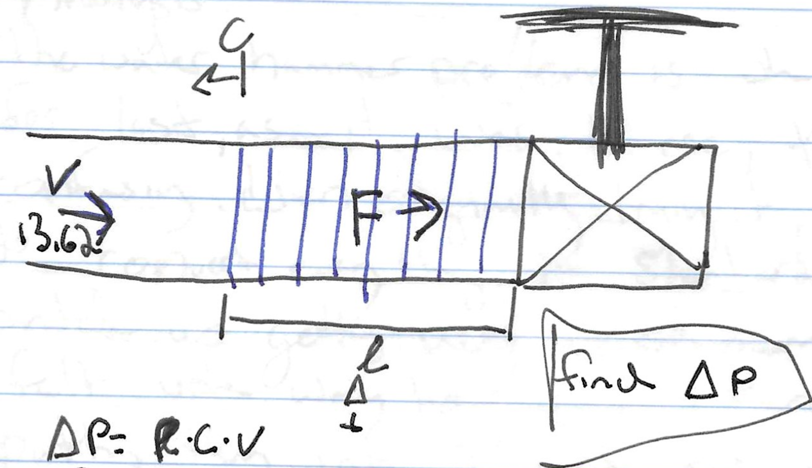
Part D analysis

for Part D, the first thing I did was determine the Diameters and resulting areas from the ratio given in the problem. From here, I went to determine V_1 to plug into the Q equation. This was my first mistake. I forgot I already had calculated the velocity through the pipe previously, and mistakenly used the restricted area at the throat. I then moved to calculate the N_R and from there, the C.

When I plugged this into the equation, I got an unrealistically large number. I then realized that I used an incorrect velocity, drew another diagram to understand it better, and ran the calculations again. After this I still realized my C was dependent on the old incorrect velocity so I amended that and came to my final answer of a 1515 lb/ft drop in pressure.

This makes sense because as area contracts, velocity goes up, and pressure drops.

Part e



$\Delta P = \rho \cdot C \cdot V$

$P_{max} = P_{operating} + \Delta P$

$$C = \frac{\sqrt{E_0/\rho}}{\sqrt{1+\frac{E_0 D}{E \delta}}}$$

$\rho = 1.94$
$E_0 = 45504000$
$D = \frac{1.5}{12}$ ft
$\delta = \frac{.145}{12}$ ft
$E = 4.1 \times 10^9$ ft

$$C = \frac{\sqrt{\frac{45504000}{1.94}}}{\sqrt{\frac{45504000 \cdot \left(\frac{1.5}{12}\right)}{4.1\times10^9 \cdot \left(\frac{.145}{12}\right)}}} = 14293$$

$14293 \cdot 1.94 \cdot 13.62 = 377661$

* Try again with metric units

I'm trusting Dr Ayala that these units will cancel, I prefer moon landing units but density units are confusing

$E = 200$ gpa $= 2 \cdot 10^{11}$ N/m^2
$E_{water} = 2179$ Mpa $= 2.179 \cdot 10^9$ N/m^2
$D = .0381$ m
$\rho = 1000$ kN/m^3
$\delta = 0.00368$

$$C = \frac{\sqrt{\frac{2.179\times10^9}{1000}}}{\sqrt{\frac{2.179\times10^9 \cdot .0381}{2\times10^{11} \cdot .00368}}} = \frac{1476.14}{.3398}$$

C → m/s

$4{,}345$ m/s $\cdot 1000 \cdot 4.15 = 1.8\times10^7$ $\frac{Kg}{ms^2}$

Analysis

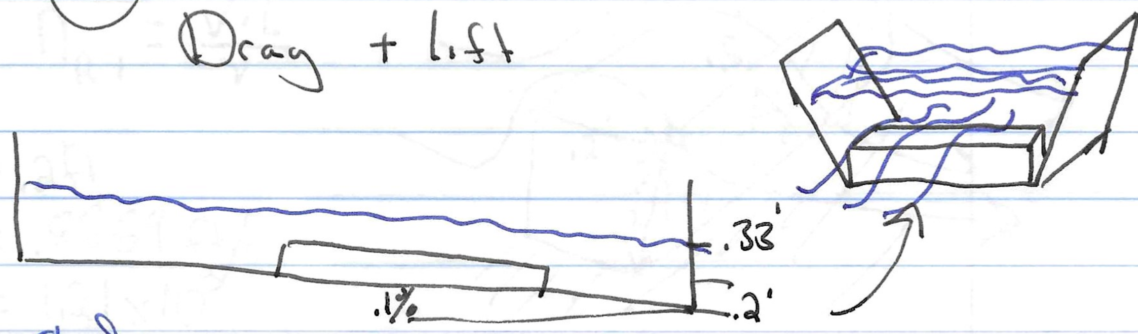
The water hammer problem is what I saved for last, as it was, to me, the most confusing. When originally trying it, I attempted to convert everything to standard units, but ended up getting very weird numbers that I felt were way too large. I then attempted putting them into SI units and while the number I got was also unexpectedly large, I am more confident in it.

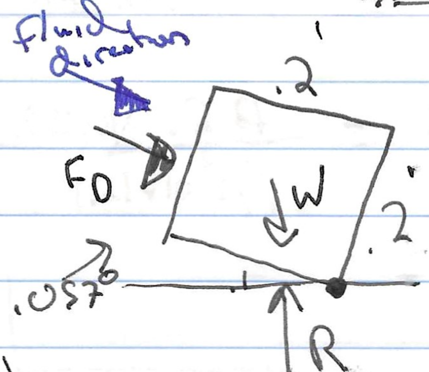
To solve the problem I used a direct application of the formula given to us in class. The question was asking for the change in pressure due to the water hammer, which was ΔP in the second equation given to us.

given the resultant ΔP, and the substantial pressure drop, I can predict there will be cavitation in the system following to the rapid closure of the valve

Part (f)

Drag + lift





* assumptions *

- * Log is stuck perpendicular to flow direction, to eliminat the Length ~~[illegible]~~ variable. Max length of the bottom of the channel is .5', so the Log is .2' × .2' × .5'
- * fluid is incompressible
- * Iso thermal Process
- * Steady State

Data:

Weight of log =

$V \cdot D = M \cdot G = W$

$.02\,ft^3 \cdot 51.83\,lb/ft^3 \cdot 32.2 = 33.37\,lb/m$

Water @ 60°F

$\gamma = 62.4$

$\rho = 1.94\,slug/ft^3 = 62.4\,lb/ft^3$

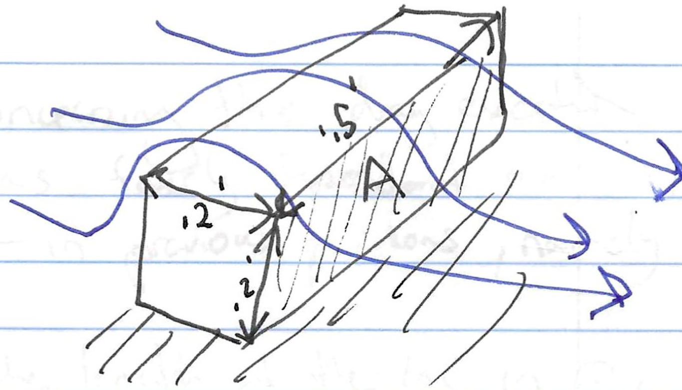
$\nu = 1.21 \times 10^{-5}\,ft^2/s$

* Solving for F_D

$$F_D = C_D\left(\frac{\rho V^2}{2}\right)A \qquad \eta_R = \frac{VL}{\nu}$$

Velocity of water through open channel

$$Q = AV \therefore V = \frac{Q}{A} \therefore V = \frac{.1671\,ft^3/s}{.1884\,ft^2} = .8869\,ft/s$$

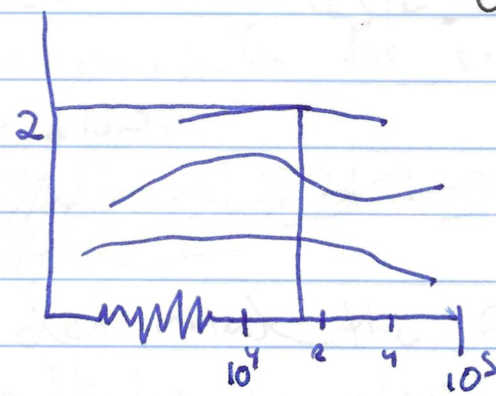


For $N_{R1} = \frac{V \cdot L}{\nu}$

$L = .2 ft$
$V = .8869 ft/s$
$\nu = 1.21 \times 10^{-5}$

$N_R = \frac{.8869 ft/s \cdot .2 ft}{1.21 \times 10^{-5} ft^2/s} = 14659.5 = 1.4659 \times 10^4$

Using Figure 17.4 in the text



$C_D \approx 2.00$ * aprox, can be canged through iteration

SO: $F_D = C_D \left(\frac{\rho v^2}{2}\right) A$

Area is drag area, so
$A = .5 \times .2 = .1 ft^2$
$\rho = 62.4 lb/ft^3$
~~$\nu = 1.21 \times 10^{-5}$~~
$V = .8869 ft/s$

$F_D = 2 \cdot \left(\frac{62.4 lb/ft^3 \cdot .8869 ft/s^2}{2}\right) .1$

$F_D = 4.9 lbs$

$C_D = 2$

$F_D \cdot d_D - W \cdot d_W = 0$

$d_D = .2/2$
$d_W = .2/2$
$W = 3.337$

$2 \left(\frac{62.4 \times v^2}{2}\right) \cdot .1 \cdot .1 - 33.37 \cdot d$

$.664 v^2 - 3.337 = 0$

$v = 2.24 ft/s$

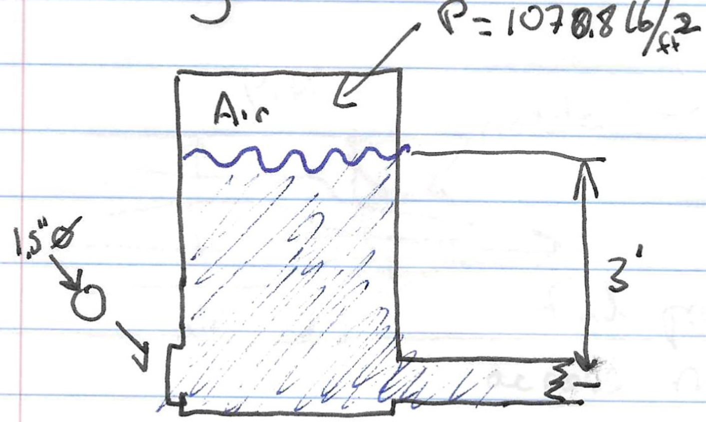
This problem concerning the drag exerted on a stuck log was fairly dependent on the answers found in previous questions, namely part a.

While I neglected the length of the log in ⓐ, I had to assume the length here to determine drag area. From the table 14.3 in the text, I determined the width of the bottom of the channel, then through logic determined that must be the max length for something to get stuck perpendicular to flow.

~~[illegible] determining things that ultimately [illegible]~~

I determined the force that would be exerted on the log by algebraically determining N_R, and therefore C_D. With the velocity of the water, the max force exerted on the log was then calculated. In addition, I also calculated the velocity required to free the log by following the trailer example.

Part g



$h_c = 3'$

$A = \frac{1.5}{12}^2 \cdot \frac{\pi}{4} = 0.01227 ft^2$

* from γh equations, we know

$p_{air} + \gamma_{water} \cdot height_{water} = p$

Since I already ran Bernoullis in part 6, I know that $P_{air} = 1070.8\ lb/ft^3$

∴

$1070.8 \frac{lb}{ft^2} + 62.4 \frac{lb}{ft^3} \cdot 3' = 1258 \frac{lb}{ft^2} = p$

$F = p \cdot A \qquad F = 1258\ lb/ft^2 \cdot 0.01227 = \boxed{15.43\ lbF}$

Going into this problem, I had already ran Bernoulli's to find the pressure in the tank previosly. from then, it is a very straightforward γh equation, then finding the pressure on the area of the flange. Since the center of the flange is 3' below the waterline, no other pressures need to be calculated - It's as if the flange was at the bottom of the tank

The location of the force on the flange is 1/3 from the bottom

Problem solution rubric

	Exceeds Standard	Meets Standard	Approaches Standard	Needs Attention
	4	3	2	1
	10 points	7 points	4 points	0 points
1. **Purpose** 5%	The purpose of the section to be answered is clearly identified and stated.	The purpose of the section to be answered is identified, but is stated in a somewhat unclear manner.	The purpose of the section to be answered is partially identified, and is stated in a somewhat unclear manner.	The purpose of the section to be answered is erroneous or irrelevant.
2. **Drawings & Diagrams** 10%	Clear and accurate diagrams are included and make the section easier to understand. Diagrams are labeled neatly and accurately.	Diagrams are included and are labeled neatly and accurately.	Diagrams are included and are labeled.	Needed diagrams are missing OR are missing important labels.
3. **Sources** 5%	Several reputable background sources were used and cited correctly.	A few reputable background sources are used and cited correctly.	A few background sources are used and cited correctly, but some are not reputable sources.	Background sources are cited incorrectly.
4. **Design considerations (assumptions, safety, cost, etc)** 10%	Design is carried out with applicable assumptions and full attention to safety and cost, etc.	Design is generally carried out with assumptions and attention to safety, cost, etc.	Design is carried out with some assumptions and some attention to safety, cost, etc.	Assumptions, safety and cost were ignored in the design.
5. **Data and variables** 5%	All data and variables are clearly described with all relevant details.	All data and variables are clearly described with most relevant details.	Most data and variables are clearly described with most relevant details.	Data and variables are not described OR the majority lack sufficient detail.
6. **Procedure** 25%	Procedure is described in clear steps. The step description is in a complete and easy to understand short paragraph.	Procedure is described in clear steps but the step description is not in a complete short paragraph.	Procedure is described in clear steps. The step description is in a complete short paragraph but it is difficult to understand.	Procedure is not described in clear steps at all.
7. **Calculations** 20%	All calculations are shown and the results are correct and labeled appropriately. The units of all values are shown.	Some calculations are shown and the results are correct and labeled appropriately.	Some calculations are shown and the results labeled appropriately.	No calculations are shown OR results are inaccurate or mislabeled.
8. **Summary** 5%	Summary describes the design, the relevant information and some future implications.	Summary describes the design and some relevant information.	Summary describes the design.	No summary is written.
9. **Materials** 5%	All materials used in the design are clearly and accurately described.	Almost all materials used in the design are clearly and accurately described.	Most of the materials used in the design are clearly and accurately described.	Many materials are described inaccurately OR are not described at all.
10. **Analysis** 10%	The design is discussed and analyzed. Argumentative predictions are made about what might happen in case of change in the operation and how the design could be change.	The design is discussed and analyzed. Argumentative predictions are made about what might happen in case of change in the operation.	The design is discussed and analyzed. No argumentative predictions are made about what might happen in case of change in the operation and how the design could be change.	The design is not discussed and analyzed.