Ram Pump, Fall 2017

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Abstract

The Fall 2017 Ram Pump subteam worked on mathematically modeling the ram pump's mechanical behavior. Experiments conducted the previous semester proved that the ram pump does not operate as anticipated or desired. Ideally, modeling will explain this unpredicted behavior. With this knowledge, the team will be able to produce a more efficient and effective design. The team found a way to derive the forces involved in the pump, but more work needs to be done to determine what the optimal spring force is for the system.

Introduction

The Ram Pump is a pump that drives water to a higher elevation without using electricity. The Ram Pump team is important to the AguaClara design because it lessens the workload of the plant operators. The ram pump eliminates the need to carry buckets of water up many flights of stairs for use in chemical stock tanks, as seen in Figure 1.

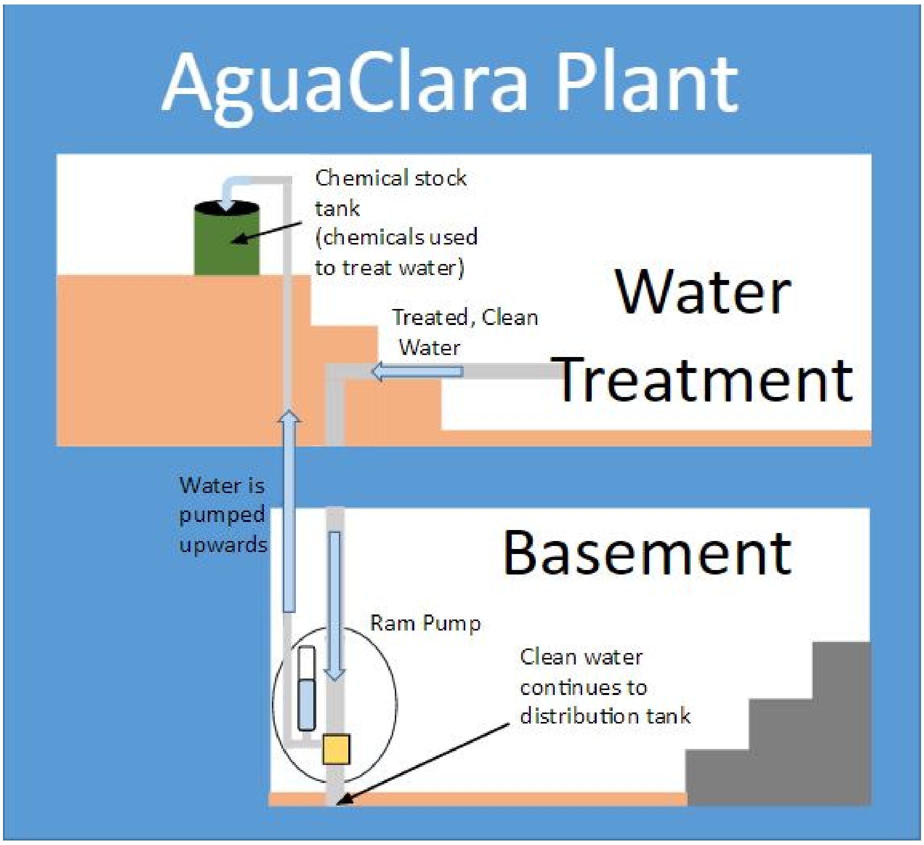

Figure 1: This image shows the overall concept behind the implementation of the ram pump design. Treated water flowing from the plant above reaches the pump below where it is then delivered back to the beginning of the treatment process. This allows coagulant and chlorine tanks to be replenished autonomously.(Aggarwal and Guzman, 2016)

Below is a schematic of the ram pump for reference, and the individual components are labeled:

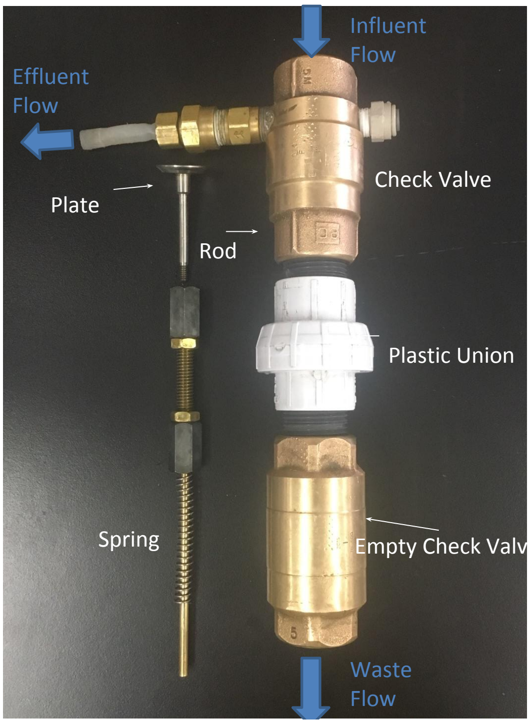

Figure 2: This image shows the overall set up of the ram pump itself (Galantino et al., 2016)

Figure 2 shows the set up of the ram pump itself, depicting how water flows through the system. The rod pictured would be inside the check valves. Figure 3 is a more detailed depiction of the inner workings of the spring and check valve, throughout a pumping period.

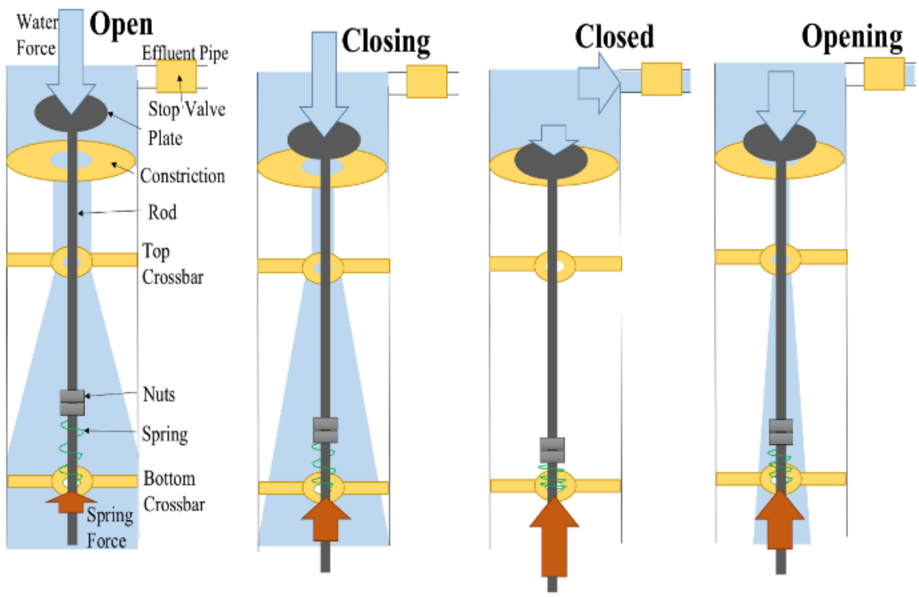

Figure 3: This image maps out the ram pump in action. While the plate is open, the hydrostatic force of a water column from above combined with a suction force acting downward cause the plate to close and the spring to compress. When the plate slams shut, the water column decelerates, resulting in a pressure increase above the plate. This causes the stop valve to open and a stream to travel upward through the effluent pipe. As the effluent stream accelerates passed the stop valve, the pressure above the plate decreases. The compressed spring exerts an upward force on the closed plate, which then opens, and the cycle repeats. (Galantino et al., 2016)

The team's basic understanding of the inner workings of the ram pump is that water travels through the drive pipe and when the force of the water pushing down on the plate is great enough, the plate will close on the constriction. The water then accelerates through the effluent pipe, and this increase in fluid velocity causes a decrease in pressure, allowing the spring force to push the valve back up again. The cycle then continues.

Little is known about the mechanics of AguaClara's ram pump. Previous teams have worked on perfecting the design in order to make the pump more efficient, but now the team has come to a point where progress in perfecting the design cannot be completed without understanding the dynamics of the pump. Based on previous works, the current team conjectured that the pump's efficiency is largely limited by the plate not staying shut long enough. This semester, the team focused primarily on modeling the pump mathematically by examining research performed on horizontal ram pumps and determining the forces involved in AguaClara's ram pump design. Only then can the team can move forward in designing a more efficient ram pump.

Literature Review

The hydraulic ram pump is one of many hydro-powered devices that was conceived centuries prior to electrical power. Ram pumps are typically utilized in settings where there are preexisting steady, continuous fluid flows to power them, such as streams or rivers. In such settings, the ram pump can intake the flowing fluid into a reservoir with two outlets, a waste valve that re-feeds into the original input stream, and a delivery valve that feeds into the desired output location (usually a storage tank). As fluid feeds into the reservoir, it flows out the waste valve until flow increases, at which point the waste valve closes. With the waste valve shut, pressure builds in the reservoir, eventually opening the delivery valve (also known as the effluent valve) and forcing water up to the storage tank, where it can be used for plumbing, chemical stock tanks, and more. The waste valve is then reopened by an oscillatory mechanism, in the AguaClara team's case a spring, but in others a weighted gate. The reopening of the waste valve is paired with the closing of the delivery valve and the process repeats. Thus, a relatively large volume of water with high kinetic energy can be manipulated to pump a small volume of water to a higher elevation.

It is difficult to find relevant literature because there is not a great deal of research about ram pumps. One of the very few exceptions to this is Mohammed's report. This report references the history of physically modeling ram pump behavior, beginning with Krol's 1951 article, which established the computations required to manipulate automatic hydraulic ram behavior. These computations were based on required values for the loss of head due to the impulse valve, drag coefficient due to the impulse valve, loss of head in the pipe, and head lost during period of retardation. Mohammed goes on to derive design parameters, referencing common fluid dynamics concepts, like Reynolds number, roughness, Blasius equations, Darcy-Wersbach formulas, etc. As such, the ram pump team can use this as a reference for fluid dynamic principles to model the current ram pump situation.

Additionally, Mohammed has a detailed visual diagram that follows the entire pumping process. The ram pump team intends to model AguaClara's pump similarly; thus this is a good reference for the team.(Mohammed, 2007)

Ninawe's article on computation fluid modeling of ram pumps has also drawn the ram pump team's attention. In this article, Ninawe and his team develop two ram pumps and compare them with a computational fluid dynamics software. They modeled these designs in Pro-E, using unstructured meshes. Then the team developed boundary conditions based on inlet velocity, inlet mass flow, outlet mass flow, and wall boundary conditions for the rest of the pump. This model was run through Ansys's FLUENT solver, producing valuable information about the flow through the pump. Ninawe's team used this method to prove which design was superior, though they do not share how the properties of each design varied. This is valuable information because AguaClara can potentially model the ram pump in Ansys as well, to assist in developing a mathematical model for the flow.(Ninawe et al., 2015)

Previous Work

Previous ram pump teams made many adjustments and conducted extensive experiments to operate the ram pump as efficiently as possible. Last semester, the main focus of the team was to determine which parameters allow the pump to operate at minimal driving head. Three specific parameters were evaluated: spring stiffness, plate amplitude (top standoff displacement), and initial spring compression (bottom standoff displacement). The following diagram illustrates the internal structure of the pump:

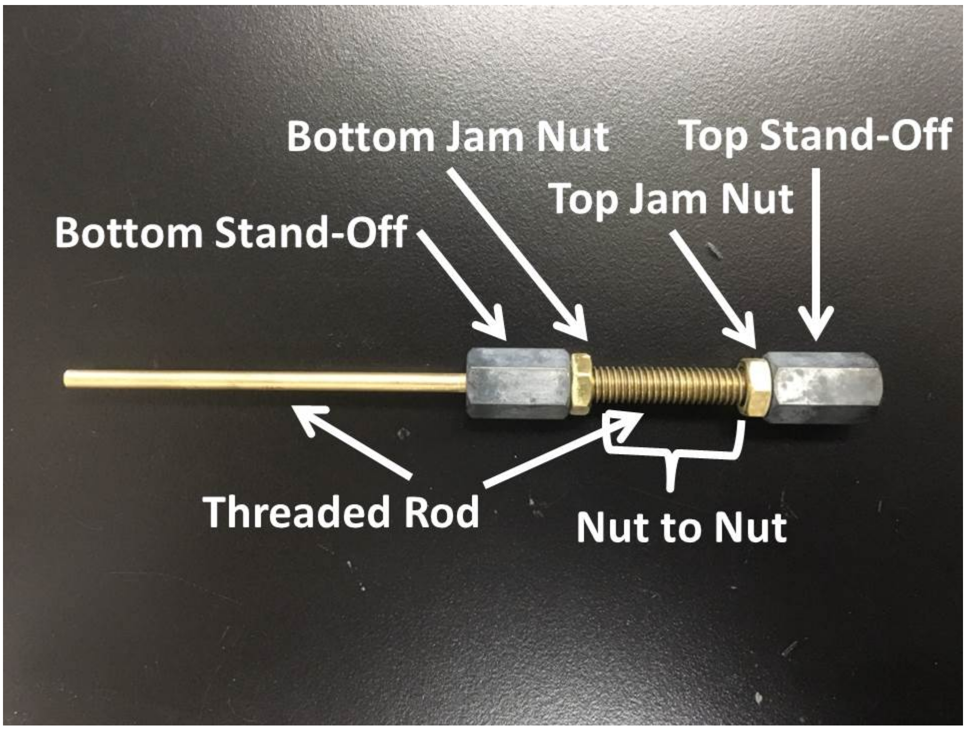

Figure 4: Labeled diagram of the ram pump internal structure for reference: the standoff and jam nuts are moved up and down the rod to change the amplitude of the plate movement and to manipulate initial spring compression and collar distance. (Galantino et al., 2016)

Top Standoff Displacement

In testing the three parameters, the team began with constant initial spring compression (with the the bottom standoff in the zeroed position) and constant spring stiffness (using the spring from the previous semester). The original initial compression graph had a vaguely parabolic from, as can be seen in Figure 5.

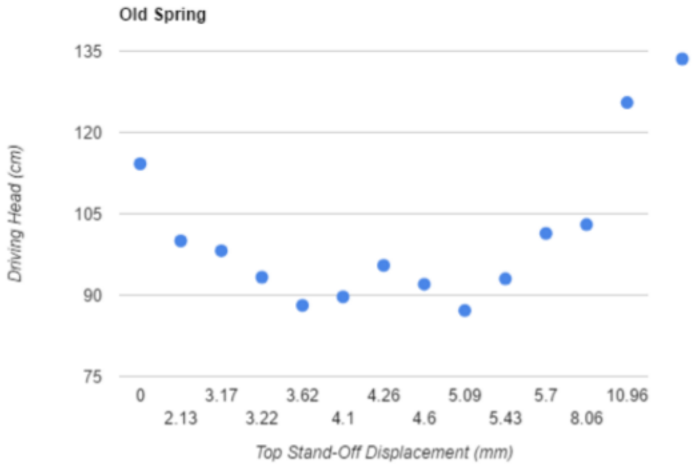

Figure 5: This shows the team's original test data on the spring from Fall 2016, using Google Sheets to generate the plot, which produced misguided results.

As this data collection continued, the team tested top standoff displacements near the optimal values, hence the concentration of data points between 3.0 mm and 5.0 mm. Unfortunately, this was misguided because the team did not realize that Google Sheets evenly spaces all data points, regardless of their numeric proximity, skewing Figure 5 until the values were plotted in Excel. Plotting in Excel resulted in Figure 6, below. This exemplifies the lack of correlation in the data.

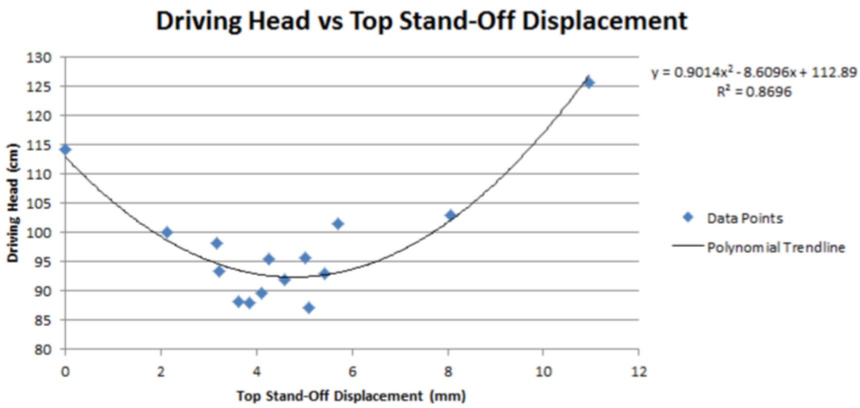

Figure 6: This is the same data as in Figure 5, but plotted in Excel which properly scaled the Top Standoff Displacement distances.

The team referred to the spring used in the Fall 2016 setup as the prodigal spring. The prodigal spring stiffness was measured at approximately 1.4 lb/in. Further testing was conducted to determine the relationship between failure driving head and top standoff displacement of the pump assembled with the prodigal spring. Based on the graphic displayed in Figure 7, there is a weak correlation between top standoff displacement and failure driving head of the prodigal spring. Thus, the team concluded that top standoff displacement has little influence on failure driving head.

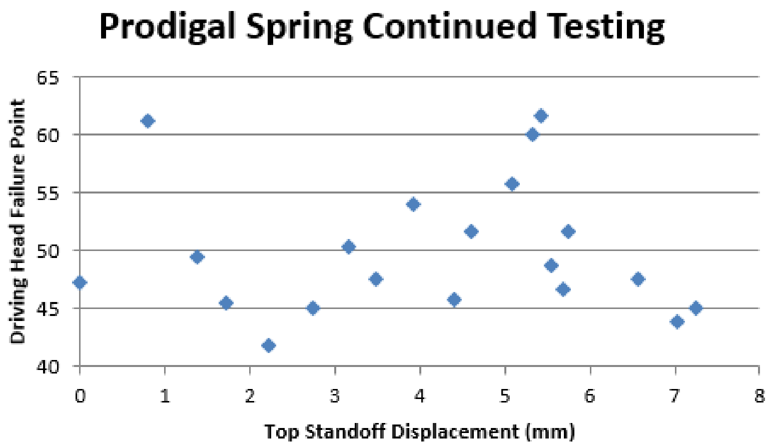

Figure 7: The following graphic displays the continued testing of the prodigal spring. Due to this graph, the team concluded that there is no real correlation between top standoff displacement and failure driving head.

Spring Stiffness

The team purchased four springs of different stiffness in order to determine the effect of spring stiffness on failure driving head. The four springs purchased had listed stiffness values of 1.1 lb/in (Spring 1), 1.4 lb/in (Spring 2), 2.49 lb/in (Spring 3), and 2.79 lb/in (Spring 4). All four springs were trimmed down to 2 inches prior to testing.

Bottom standoff displacement tests began at a minimum 1.1 cm displacement value, which increased by 0.2 cm for each test. The testing range was constrained by the length of the threaded part of the rod, the length of the spring and the length of the bottom standoff. The data from this testing can be viewed in the graph below in Figure 8. The prodigal spring was 2.5 inches long during plate amplitude tests but was then cut to 2 inches for bottom standoff displacement testing to eliminate variation when comparing between all of the springs. The data revealed that Spring 4 was stiffer than Spring 3, which is inconsistent with the respective values provided by the manufacturer.

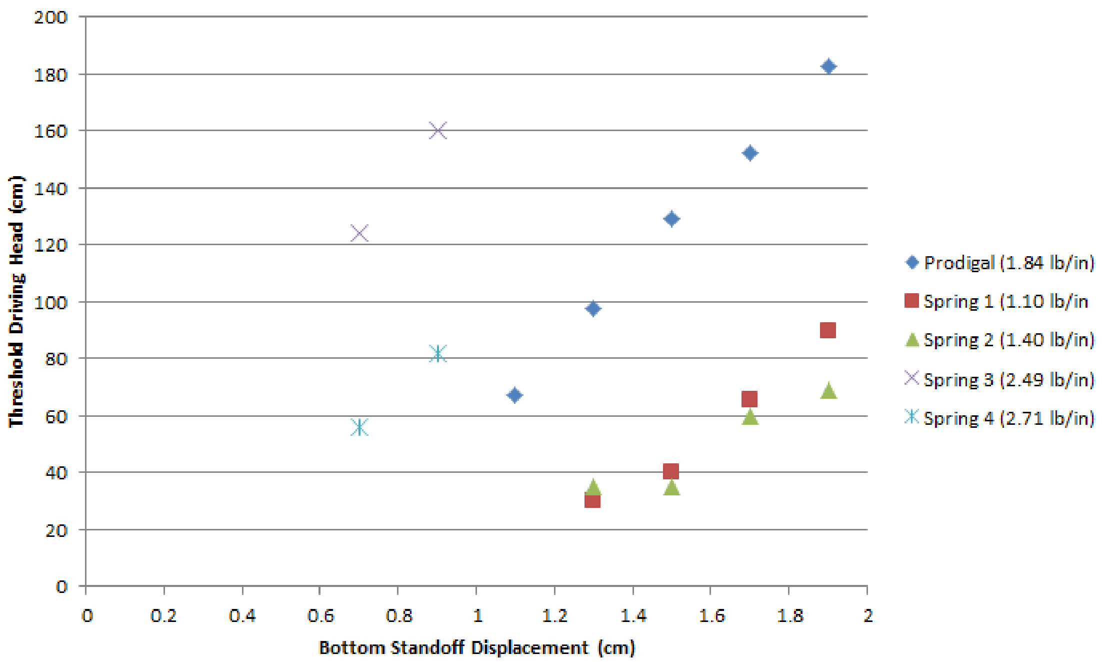

Figure 8: This graph shows the relationship between spring stiffness and the functional driving head threshold. Notice that the weaker the spring, the less driving head required for proper functioning.

The spring constants for the four tested springs were evaluated through compression testing. These experimental values counter the previous discrepancy. 8 The Spring 2017 team ultimately determined that there must be another factor for stiffer springs that caused the anomaly in the previous data. 8

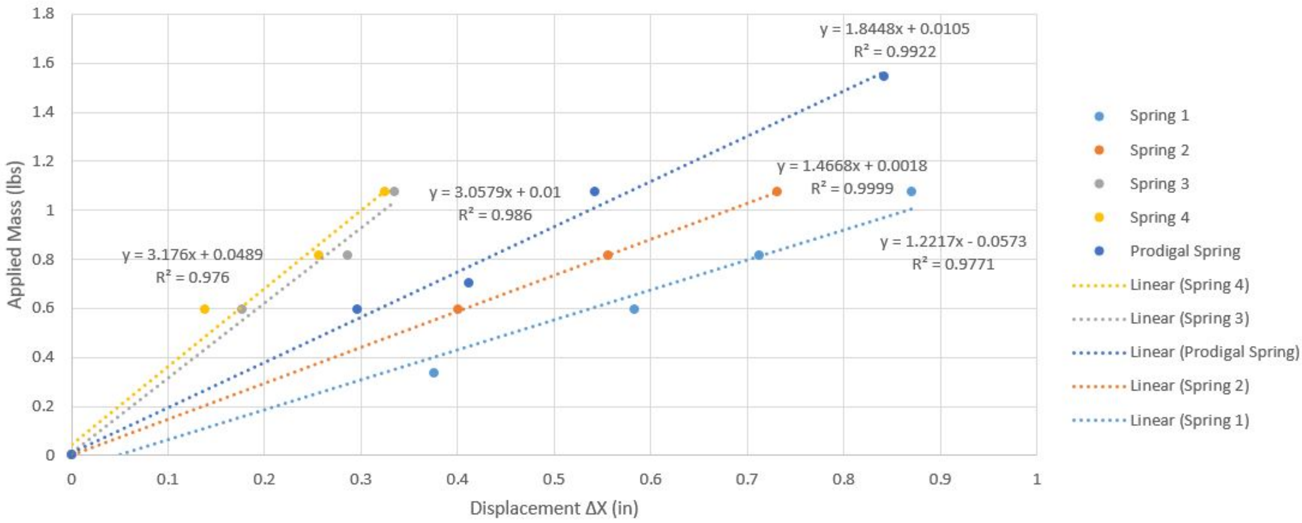

Figure 9: The following graph shows the spring constants that were measured through spring compression testing

Mathematical Modeling

The Spring 2017 team attempted to mathematically model the ram pump after completing experimentation to compare the result to that of the experimental data. To begin, the team modeled the ram pump as a first order mechanical system, with a force acting on a mass, attached to a fixed spring. The force of the spring was modeled as kx(t), where k is spring stiffness and x(t) is a time dependent function for the spring elongation/compression. The force of water was modeled statically as a column of water, creating a force equivalent to ρgh, where ρ is the density of water, g is the force of gravity, and h is the height of the water. As represented in Figure 10, the team initially hypothesized that the plate would begin reopening when the potential energy from the column of water was equivalent to the potential energy of the compressed spring.

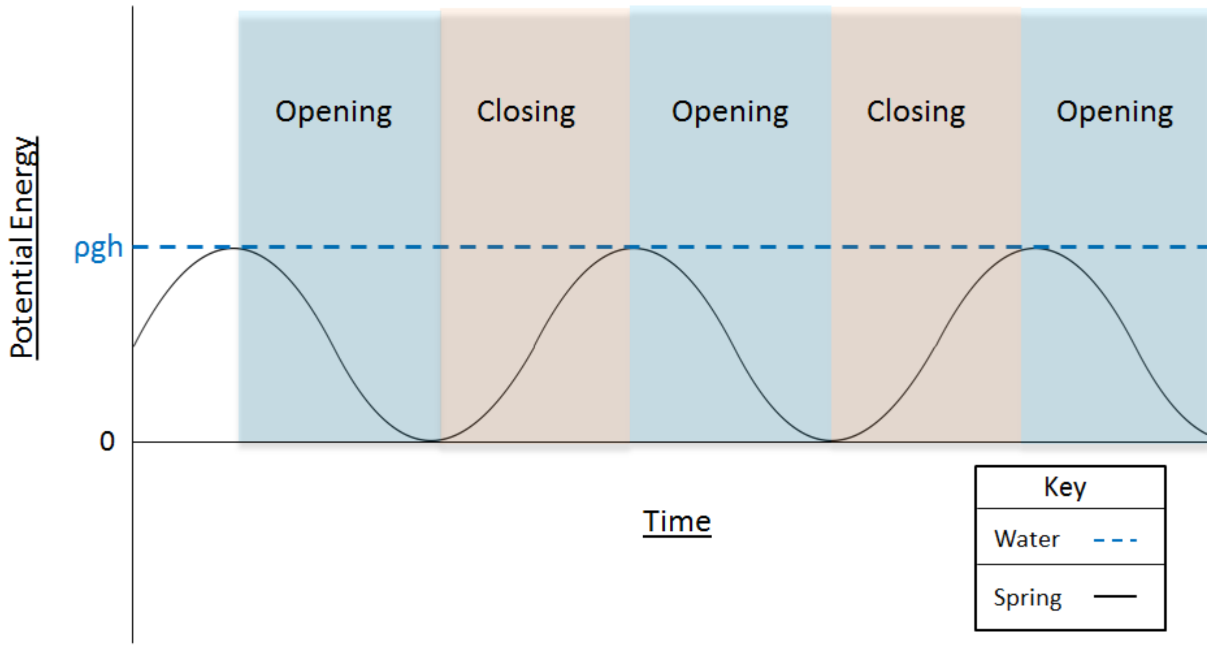

Figure 10: This graph represents the teams initial incorrect hypothesis.

After discussing the findings with advisors, the team determined that the force of water should be modeled dynamically and the change in fluid velocity above the plate with respect to time must be taken into account.

Methods

The team is focused on developing a mathematical model of the ram pump: most work has centered around reading and problem-solving. To start, the team analyzes the pump as a force balance, pressure problem, and momentum balance. These analyses make it clear that there are forces acting in the system that the team does not currently know how to model or calculate. In search of understanding those unknowns, the team has been reading articles and studying other ram pump or constricted spring models. Throughout this process, the team members share and analyze the possibilities together as they discover new concepts or develop new theories.

Experimental Apparatus

The team did not gather any empirical data this semester, but used the ram pump setup displayed below (Figure 11) for mathematical modeling.

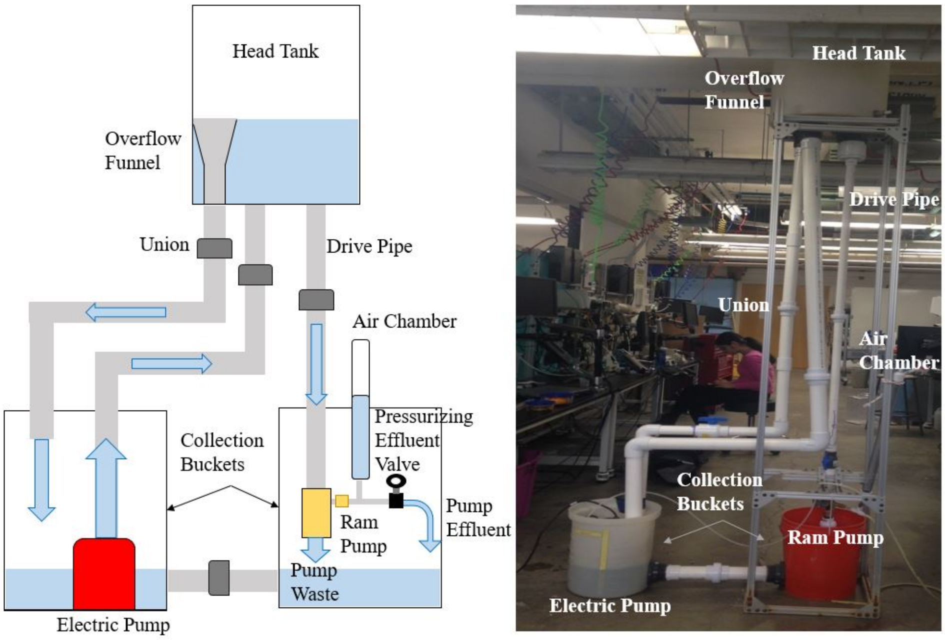

Figure 11: The electric sump pump delivers water to the head tank at the top of the system. From there, the water flows down the drive pipe and into the ram pump itself. While most of the water exits through the bottom as pump waste, a portion is pumped as effluent. The current team aims to mathematically model this process.(Aggarwal and Guzman, 2016)

Procedure

Procedure for hypothetical experiment described above will be developed after more modeling work.

Results and Analysis

The team has been working to develop a comprehensive understanding of what is currently understood, what can be surmised experimentally, and what requires more research.

Spring Constant Analysis

Firstly, in analyzing the inconsistency with spring constants from the previous semester, the current team derived an equation which proves that cutting a spring actually changes the spring constant k. The equation explains the inconsistencies previous sub-teams had been running into with their springs.

The current team started with the force of a spring, where F is the force from the spring, k is the spring constant (a characteristic of the spring), and δx is the displacement of the spring (the original length minus the current length),

$$F = kx$$

then brought in the stress strain equations, where E is the elastic modulus of the spring, σ is the stress, ϵ is the strain, F is still the force, A is the area the force is applied to, δ x is still the displacement, and L is the original spring length

$$E = \frac{\sigma}{\epsilon} = \frac{\frac{F}{A}}{\frac{\delta x}{L}}$$

Combining this with the first equation results in:

$$F = kx = \frac{EAx}{L}$$

Thus

$$k = \frac{EA}{L}$$

Considering a spring that is length L_o, which is then cut to a quarter of its original length:

$$L_n = \frac{L_o}{4}$$

.

This gives a new k, which is referred to as k_n.

$$k_n = \frac{EA}{\frac{L_o}{4}} = \frac{4EA}{L_o}$$

Thus $k_n = 4k_o$. This explains the discrepancies between the measured and advertised spring constant values, as the team had cut the springs to uniform length and ignored the corresponding effect on the spring constants. This will impact future experimentation when computing forces based on k values, and the team will adjust accordingly if any lengths are altered.

When watching the video that the previous semester's team made of the ram pump in slow motion, it is found that the plate remains open for a while whereas the plate closes for a minutely short amount of time. The team hypothesizes that this is due to the fact that the plate is constrained by the bottom of the valve. Perhaps if the plate were able to move between the two extremes freely (being completely open and completely closed), the plate would close for a longer amount of time.

Currently, the team has been focusing on when the plate is completely open and completely closed because, at those moments, the plate is not in motion and can be treated as a static problem, (even if it is a very short amount of time). Initially, the team thought that the force of the column of water should equal the spring force when the plate is closed, but this did not account for the decrease in pressure from the water leaving the valve. When the plate is completely opened, there is a drag force and suction force around the plate causing the plate to slam shut. Additionally, the spring force is also equal to zero because at that point the spring is not compressed at all.

Velocity Analysis

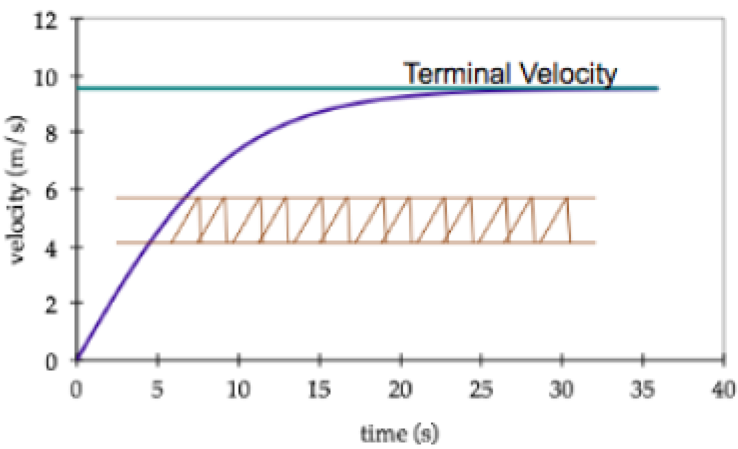

Figure 12: This image shows the velocity profile of the ram pump

As the water flows through the drive pipe, it accelerates such that the velocity increases and therefore the pressure in the waste valve increases. At a certain point, the valve closes which causes the velocity of the water to drastically decrease and, during this deceleration period, the water is forced to flow through the effluent valve. When the pressure decreases beyond a certain point, the valve opens and the process restarts. However, the changes in velocity cannot exceed certain limits; if the velocity is too high, unwanted loss is accumulated and if the velocity goes too low, unwanted losses due to decreased flow rate are accumulated. Furthermore, the area underneath the decreasing velocity lines represents the volume of water being pumped.

Force Analysis

The forces that are known are the force of the water column in the drive pipe and the spring force. An unknown force is the suction force due to the velocity of the water increasing around the plate. As the velocity increases around the plate, the pressure decreases behind the plate. This causes a wake. This decrease in pressure is what the team believes causes the plate to slam shut as opposed to gradually closing due to the increase in the velocity of the water above the plate. Using the energy equation, the team will model these forces in Jupyter notebook in order to solve for the acceleration of the water. Once the acceleration is found the velocity can be found. This will allow the team to calculate the amount of water being pumped.

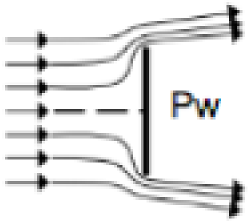

Figure 13: This image shows the convergence of the streamlines, which illustrates the velocity profile around the plate. The converging streamlines indicate that at any point behind the plate, the pressure is the same (Pw).

Computing The Suction Force

The team successfully developed an equation for the pressure and fluid velocities involved in suction. This is determined by modeling the situation when the check valve opens and remains open, hypothetically. The team created the model through a series of energy equation calculations and Bernoulli's computations throughout the system. The points in the systems used for these computations can be seen in the Figures 14 and 15 below , where P followed by a subscript denotes the pressure at a specific location of interest.

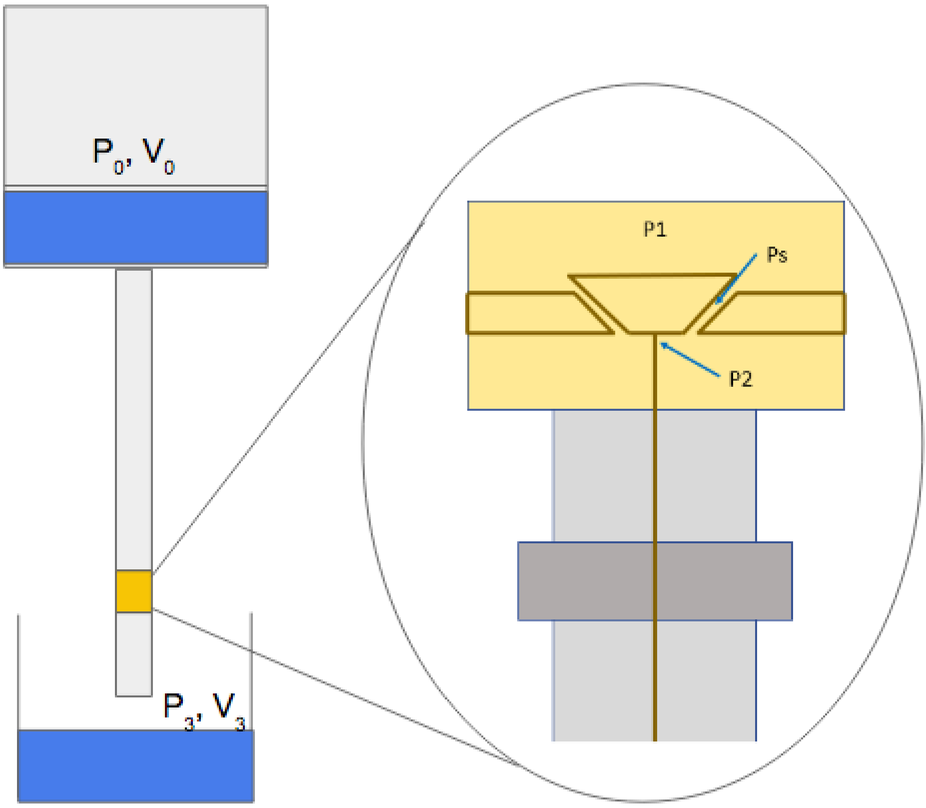

Figure 14: This displays the points of interest in the following energy and Bernoulli equations, where the pressure at each point are denoted by P with a subscript relevant to the location. This is the macro view– the next figure displays $P_1, P_2, and P_s$ in more detail.

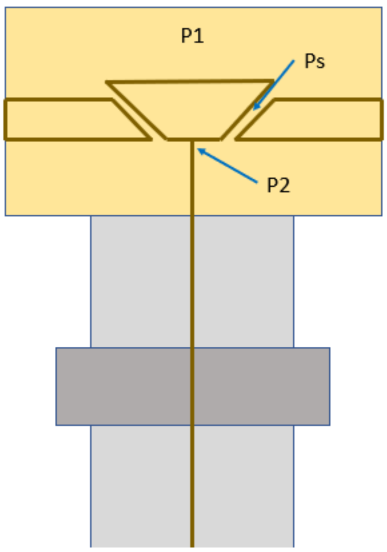

Figure 15: This displays the points of interest in the following energy and Bernoulli equations, where the pressure at each point is denoted by P with a subscript relevant to the location. This is the zoomed in view within the pump, displaying only the points of interest within the pump itself, particularly around the check valve.

In Figures 14 and 15, $P0$ is at the free surface in the bucket at the top of the systems, $P1$ is in the drive pipe above the ram pump, but very close to it ($P2$) is directly below the check valve, and Ps is in the slit between the plate and the holding structure, where water flows only when the valve is open.

The team then calculates the flow, Q, using the flow pipe function in the physchem folder of AguaClara's aide design repository. This returns the flow through a vertical pipe, incorporating both major and minor losses in turbulent or laminar flows. The Q value obtained from the physchem function is the maximum Q value, which occurs at the theoretical terminal velocity, which the teams experiment never reaches. This function requires a great deal of inputs including the geometry, the major and minor head loss, and pipe roughness. The geometry can be measured by hand and the roughness is assumed to be around 1 for a smooth PVC pipe.

To compute the major head loss, the team manipulates the energy equation between the two free surfaces in the system, at locations 0 and 3.

$$\frac{P_0}{\rho g} + \frac{V_0^2}{2g} + z_0 = \frac{P_3}{\rho g} + \frac{V_3^2}{2g} + z_3 + h_L$$

Where P_0 and P_3 are both P_{atm} , because they are free surfaces, V_0 and V_3 are the same because $V = \frac{Q}{A}$ where Q is the same throughout the whole system, and A is the same at each point because the bucket and the top of the system is the same as the bucket at the bottom of the system. This reduces the equation to

$$h_L = z_0 - z_3$$

Where z_3 and z_0 are measurable heights, allowing the team to solve for h_L.

To solve for the minor loss coeffient, k, the team uses the following equation for each constriction/contraction throughout the system, then computes the summation.

$$k_1 = (\frac{A_{drivepipe}}{A_{topbucket}} - 1)^2$$

$$k_2 = (\frac{A_{drivepipe}}{A_{checkvalveslit}} - 1)^2$$

$$k_{tot} = k_1 + k_2$$

Having solved for the all of the inputs needed to solve for Q, the flow rate throughout the system is found. Attaining this Q value allows the team to solve for the fluid velocity at any point in the system where the geometry is known, in that

$$Q = VA$$

Where Q is the flow rate, V is the fluid velocity, and A is the cross sectional area perpendicular to the flow at any given position in the system.

This enables the team to manipulate the energy equation between point 0 and point 1 in the system.

$$\frac{P_0}{\rho g} + \frac{V_0^2}{2g} + z_0 = \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 + h_L$$

Solving for P_1 results in

$$P_1 = P_0 + \rho * (\frac{V_0^2}{2} + z_0 g - (\frac{V_1^2}{2} + z_1 g + h_L g))$$

Where z_0 and z_1 are measured vertical heights of the two locations, P_0 is assumed to be P_{atm}, h_L is computed with the aide design function for head loss, and V_1 and V_0 can be computed using the Q value and measured cross-sectional areas at each point, as mentioned earlier.

Thus, with P_1 as a known value, Bernoulli's equation can be used between location 1 and the slit location to compute the pressure in the slit, P_s. Assuming the height difference between P_1 and P_s is negligible (because of how tiny it is), this results in

$$P_s = P_1 + \rho * (\frac{V_1^2}{2})$$

Subsequently, P_2 can be approximately equated to this P_s value because of the stream line dynamics associated with the wake of an object like the check valve, as can be seen in 13.The basic concept is the

the pressure in the immediate wake of an object is approximately equivalent to the pressure immediately along the side of the object.

This allows the team to compute the suction force as intended, in such that

$$F_{suction} = P_2 * A_s$$

Where A_s is the cross-sectional area of the slit perpendicular to the flow.

From the calculations in python, the team finds, when the water in the drive pipe is at terminal velocity, maximum suction force is equal 3.551 N for the current lab system set up.

Calculating Time Intervals

The team also calculated the ideal amount of time the plate should be closed. This is determined using the velocity profile graph. Looking at Figure 12, the amount of water pumped is the area under the decreasing velocity line. The team sought to find the time that would need to take place in order to maximize the water pumped. The values for the maximum and minimum velocities are estimated to be about half of the terminal velocity and a quarter of the terminal velocity. The team is unsure of how to choose these values for the velocities, but perhaps once a velocity time graph can be established for the ram pump, the values can be obtained.

To find the ideal δt, the acceleration is found using Newton's second law of motion F=ma. The force is taken to be the force of the water on the plate when the plate is closed. The team calculates the mass by finding the volume of the water above the plate and multiplying this by the density. Once acceleration is obtained, the team knows that since

$$a = \frac{\Delta v}{\Delta t}$$

the team is able to calculate δt to be equal 0.4846 seconds based on the assumptions made.

To compute the ideal amount of time the plate should be open, the team continued to use $0.25V_{max}$ as a minimum and $0.5V_{max}$ as the maximum velocity. Subsequently the team assumed that, when the plate is open, the acceleration of the water is equivalent to gravity, allowing the team to calculate the time frame as follows

$$a(t) = 9.8m/s^2 = \frac{V_2 - V_1}{t_2 - t_1}$$

$$\Delta t = t_2 - t_1 = 9.8m/s^2 * (V_2 - V_1)$$

Where t_1 is equivalent to the time the plate must be closed, assuming the period starts as soon as the plate is closed. Thus, plugging the values into Python , the team found that the plate should be closed 0.1074 seconds. Using gravity as the acceleration value ignores head loss in the system, but this is acceptable because we are operating at sufficiently low velocities. When operating at velocities closer to the terminal velocity, one must employ a hyperbolic tangent function. In avoiding head loss, the team also avoided hyperbolic tangents.

Other Force Calculations

Right when the plate closes, there is still a force acting on the bottom of the plate due to the hanging column of water that entered that space prior to the plate closing. This can be computed by an energy balance between point 2, from Figure 14 and the free surface at point 3. This results in

$$\frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 = \frac{P_3}{\rho g} + \frac{V_3^2}{2g} + z_3 + h_L$$

P_3 is P_{atm} because it is a free surface, h_L is not a concern because there are no constrictions or contractions and shear should be minimal, V_3 is 0 because it is a free surface, and $V_2 = 0.5V_{max} = 0.1772m/s$ because this is the velocity of the water right as the plate closes. Knowing $z3 - z2 = 9in$ as measured in the team's experimental set up,

$$P_2 = \rho * g(z3 - z2 - \frac{(V_2)^2}{2g})$$

$$F_{hangingwater} = P_2 * A_{plate}$$

Note, P_2 has a different value prior in this report...that is because P_2 refers to pressure at a location, but that pressure varies in different scenarios at different times.

Summary of Forces

When the Plate is Closed

Analyzing the moment in time when the plate is closed and $V = 0.25V_{max}$, the top of the plate is experiencing the force of the static column of water and the bottom of the plate is experiencing the force due to the hanging column of water that passed through just prior to the plate closing, in addition to the spring force.

$$ForceonTopofPlate = \rho g h A_{drivepipe}$$

$$ForceonBottomofPlate = P_{2,closed} * A_{plate} + F_{spring,unextended}$$

When the Plate is Open

Analyzing the moment in time when the plate is closed and $V = 0.5V_{max}$, the top of the plate is experiencing the force of the static column of water, in addition to head losses due to fluid flow, and the bottom of the plate is experiencing the force due to suction, in addition to the spring force.

$$ForceonTopofPlate = \rho g h A_{plate} - h_L$$

$$ForceonBottomofPlate = F_{suction} + F_{spring,extended}$$

Spring Forces

Based on the force balances above, we computed the ideal spring forces as follows

$$ExtendedSpringForce = k\Delta x_{max} = \rho g h A_{drivepipe} - h_L - P_{2,open} * A_{plate} = 72.85N$$

$$UnextendedSpringForce = k\Delta x_{min} = \rho g h A_{drivepipe} - P_{2,closed} * A_{plate} = 12.24N$$

Conclusions

The summation of the aforementioned calculations is an understanding of the forces at play in the system such that the maximum and minimum ideal spring forces can be calculated, the forces at play can be seen in 16. The values obtained for the spring forces are clearly a bit extreme and it would be quite difficult to find a spring and and geometry that satisfied those constraints.

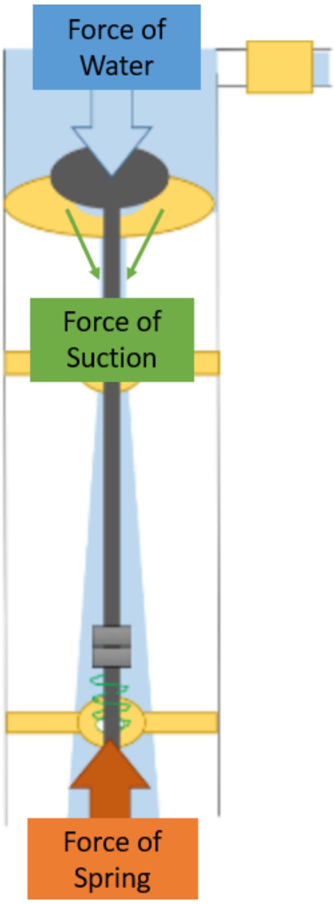

Figure 16: This depicts the major forces at play in the system, in addition to providing a vague understanding of where they act within the system.

The team investigated these strange values and found that the absurdly large value for the extended spring force was the result of the force of water acting on top of the plate when it is open, which included the hydrostatic force of the water in the drive pipe. Because the drive pipe is quite large, the volume of water in that hydrostatic column exerts 76.4 N, explaining why the spring must exert 72.85 N to overcome that force (the difference being the result of pressure below the plate and head losses).

This value is inaccurate because, in fact, there is no hydrostatic pressure acting on the top surface of the plate when the plate is open. All of the fluid potential energy is being use to accelerate the water and/or to overcome head losses. There are pressure forces acting on the top and bottom of the plate, as the team assumed, but the combined pressures do not include hydrostatic forces. Rather, the forces on either side of the plate combine to create total drag on the plate, which increases with the square of velocity, as seen below in 17

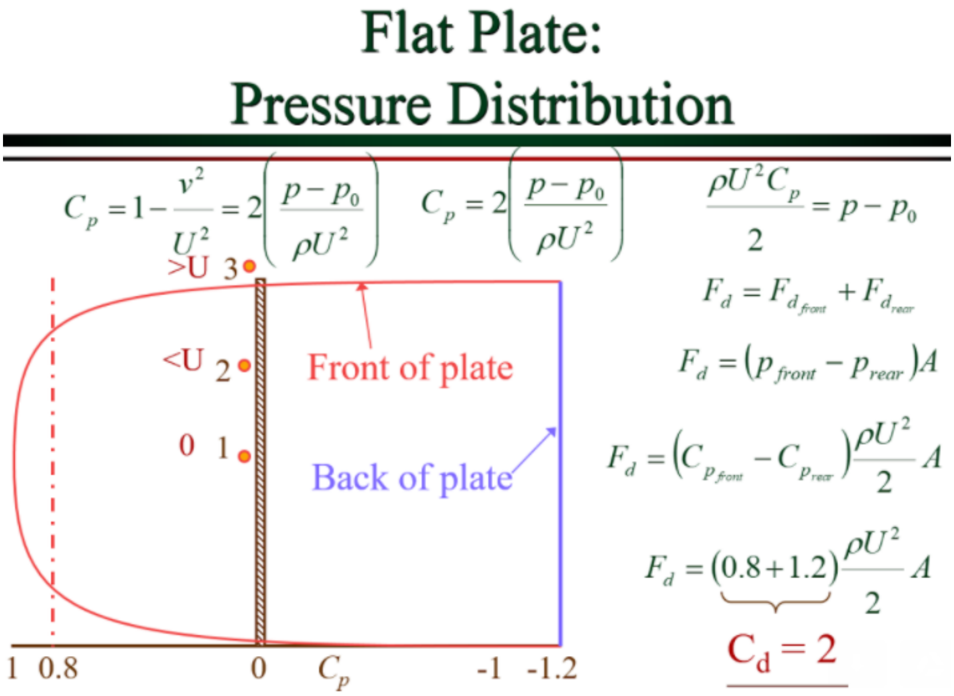

Figure 17: This shows how the team should calculate the force on top of the plate when the plate is open, as opposed to the static force calculations the team originally performed.

Future Work

The team must recalculate the forces based on the realization that no hydrostatic forces are acting on the top of the plate when it is open, using the equations in 17.

Once the team computes more valid spring forces, they will attempt to implement springs that produce those forces and see how that effects the ram pump in reality, effectively testing the model.

If this works and produces the desired open and closed times, then the team will attempt to optimize the V_{max} and V_{min} values, increasing the difference between the two, making V_{max} closer to $V_{terminal}$, which should increase efficiency.

If this does not work, the team will study the discrepancies between reality and the current model, attempting to create a more realistic model.

References

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Appendix

Semester Schedule

Task Map

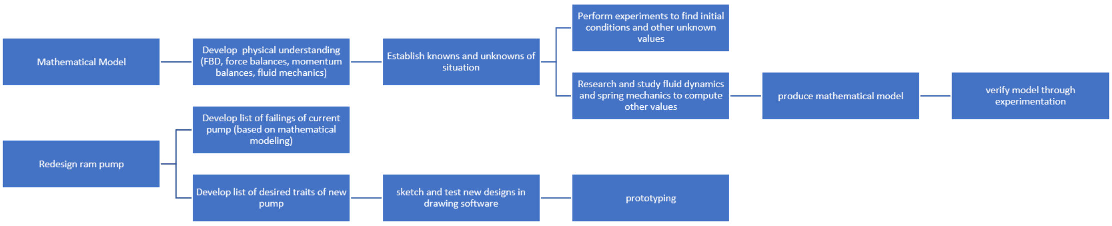

Figure 18: This shows the planned work flow for the semester.

1. Continue to do independent research through September, to firmly establish what the team knows and what the team still needs to surmise in terms of making a model...After this is established, meet with Monroe to see if he has any insights about the things the team does not know. Meet with Monroe early October.

2. Begin experimenting to find values that may be useful in modeling, such as boundary conditions. Potentially develop a pump made of clear PVC for this. Start experimentation in October, finish by end of November.

3. Using the model, establish the current designs failings and how the pump design can be manipulated to solve these problems and be improved. Finish by end of November.

Manual

The goal of this section is to provide all of the guidance that would be necessary for a future team to pick up your work where you left off. Please try to be thorough and put yourselves in the shoes of a newcomer to the project. Below are some recommended sections, but the manual will likely take a slightly different form for each team.

Experimental Methods

1. Step 1.

2. Put tasks in a sequential order.

3. It is okay to have sub-lists.

    (a) Like this.

    - Or like this.

4. It is also okay to have multiple methods (e.g., in order to describe different steps in the experiment). For example:

    #### Cleaning Procedure

    (a) Step 1.

Experimental Checklist

Another potential section could include a list of things that you need to check before running an experiment. Ideally, you would also have an Excel file for this, but you could give a more careful explanation of it here.

ProCoDA Method File

Use this section to explain your method file (`.pcm`). This could be broken up into several components as shown below:

States

Here, you should describe the function of each state in your method file, both in terms of its overall purpose and also in terms of the details that make it distinct from other states. For example:

- OFF - Resting state of ProCoDA. All sensors, relays, and pumps are turned off.

Set Points

Here, you should list the set points used in your method file and explain their use as well as how each was calculated.

Special Components

If your subteam uses a particular part that is unique and you could foresee a future subteam needing to order it or learn more about it, please include basic information like the vendor where it was purchased, catalog/item number, and a link to any documentation. For example, here is a link to the User's Manual for the model of turbidimeter most commonly used in AguaClara research.

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