Tech 797: Spring 2018

Project OASIS:

Optimizing Aquaponic Systems to Improve Sustainability

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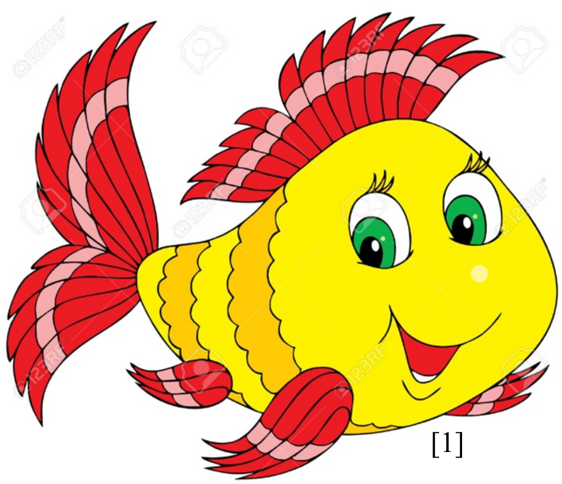

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Sea Grant New Hampshire

Abstract

Aquaponic systems are a combination of hydroponics, growing plants in water, and aquaculture, cultivating fish. Water circulates between the two subsystems, transferring the waste from the fish tank to the plant bed, where the plants absorb nutrients and filter the water for the fish tank. Small-scale aquaponic systems are of particular interest, as they are appropriate for rural and developing locations to harvest both plants and fish for a local community. Understanding the flow within the fish tank will decrease the power required to run the pump, which will improve overall sustainability. The shape of the fish tank greatly influences the flow in the tank and its initial costs. This study focused on experimentally mapping the flow in a 2m x 2m square fish tank with curved corners using four-inlet and two-inlet configurations. For each flow design, data was collected using Acoustic Doppler Velocimetry. Detailed uncertainty analysis and repeatability tests were performed to ensure the validity of the data. The ultimate goal of the study is to develop an inlet-design configuration which minimizes initial and operational costs of the small-scale aquaponic system.

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Introduction

Aquaponics, growing plants while simultaneously farming fish, allows for a sustainable way to produce resources where they might not typically be available. It combines hydroponics, the growing of plants in water, and aquaculture, the cultivation of fish. These systems operate starting with the fish tank where the fish produce waste which then goes through a radial settler and filter leading to a plant bed. The plants, grown in water instead of soil, absorb the nutrients from the fish waste and filter the water before it is pumped back into the tank, so the fish to have clean water coming into the tank. A diagram of the aquaponic cycle can be seen in Figure 1. A real-life example of an aquaponics system that is being used for research at the University of New Hampshire is seen in Figure 2 and Figure 3.

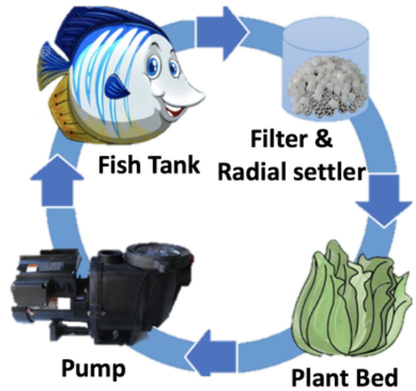


FIGURE 1: SCHEMATIC OF THE AQUAPONIC CYCLE

The popularity of small-scale Aquaponic systems has been on the rise in the last decade, despite limited research done on optimizing system design, and even less focuses on the fish tank design. This has resulted in failed attempts to better arrange the system as there is little understanding that describes how the subsystems relate to one another. The overall goal of this study is to produce an improved understanding of the individual components within the system. Using that knowledge to create an aquaponics system out of locally-sourced materials that are more cost effective than standard materials, specifically for the costliest aspect of the system, the tank. Another goal is to improve the overall efficiency of the system by reducing energy required to operate it. The largest energy consumer is the pump because it needs to move the water through the fish tank and then through the plant bed. By researching ways to lower power required to run the pump, it can then be installed in more rural areas where there are more limited energy resources. Once this is achieved the system can be implemented in developing areas at a cost-effective price, helping their community to obtain resources they wouldn't have otherwise.

FIGURE 2 (LEFT): THE FISH TANK (AQUACULTURE PORTION) FROM THE CURRENT AQUAPONICS SET UP AT UNH;
FIGURE 3 (RIGHT): THE PLANT BED (HYDROPONICS PORTION) FROM THE CURRENT AQUAPONICS SET UP AT UNH

Global Impact Statement

The main reason to start this project was to have a positive influence on the globe, specifically developing communities. Aquaponics is a very sustainable system compared to traditional gardening and fish farming, but it can be costly to build and to function properly without experimentation. Depending on the size of the unit and what resources are used, it can cost anywhere from $2,000 to $15,000+ to build a system [2]. These initial costs can make it challenging for a developing community to build one as they do not have the extra funds to dedicate to building an aquaponics system. The benefits would pay off in the long run through fresh vegetables and fish being produced, creating a consistent food source for the community. Additionally, once the tank is up and running, they will still incur additional operating costs to maintain the system. They will need to power the pump that operates the system and pay for upkeep. Many developing communities have limited, if any, power sources and what they have cannot be taken up by the pump, which, depending on the size, can consume anywhere from 200 up to 700+ kWh [2]. Additionally, if something breaks and needs to be repaired, if it is not made from a local material it can be very difficult and expensive to fix. So, while implementing an aquaponics system in a developing community can be very beneficial, there are a lot of factors preventing construction.

To make it possible for these systems to be built anywhere, Project OASIS aims to help resolve the above problems, specifically finding new ways to construct the tank out of locally sourced materials and reducing the amount of power the pump requires to operate. By better understanding the water flow within the tank and system, these goals can be achieved. Once the required amount of power has been reduced, alternate power sources for the pump will also be considered. These changes will help to make aquaponics systems even more sustainable than they already are.

Once the updates have been applied, the systems can begin to be integrated to developing communities and anywhere else that are looking to implement a sustainable gardening system. The improved aquaponic systems will allow for a steady stream of vegetables and fish to be grown for the community. It will also use less water than a traditional garden would, allowing those resources to be used elsewhere. While there will still be an initial cost, the improvements implemented by this study will reduce it and make the implementation of an aquaponics system more feasible.

Project History & Background

Project OASIS began in the fall of 2015 as an idea for a senior capstone project for students in various disciplines at the University of New Hampshire. The goal was to make aquaponic systems even more sustainable than they already were and to implement one in a community in Costa Rica. This project is now in its third year of students using it for their capstone and each year has continued to work towards the overall goals.

Goals of Overall Project

The main goal of the project is to design an aquaponics system that improves on the already high level of sustainability. The main ways this can be achieved is through designing a tank that can be built from local resources in the community, and possibly recycled materials. This can reduce the overall cost of it and make it more feasible for communities to build their own without importing lots of materials. The other focus is to lower the amount of power required to run the pump. By better understanding the flow of the water in the tank and how it relates to the power, the tank design and inlet design can be configured to reduce the power. Better understanding the water circulation will also make it easier to design a custom tank as usually they would have to be built to know if it will work, but a 3D CFD model can help check the proposed setup prior to installation.

History of Project

When this study began three years ago the focus was on making decisions for the aquaponics system as a whole, deciding on the general details for the plant beds and the fish tank. The results of those efforts can be seen above in Figure 2 and Figure 3. Since then it has shifted to focus on the fish tank, to better understand the energy needs of that specific system and to then make that part of it more sustainable. The previous groups research on this study started to focus on what the circulation within the tank looks like and how to better understand its flow pattern. By creating a model of the circulation patterns, the power required to run the pump can be minimized, thus increasing the ability to use this system in more rural areas. The previous iterations of the designs have started to implement in a small community in Costa Rica, so that it can be seen if the system is feasible in these kinds of areas.

Specific Study Goals

This present study focuses on creating an experimental procedure to better understand the water flow experimentally in the tank to work towards reducing power and correlating it to a 3D model. A new measurement and Vectrino mounting system needed to be designed to decrease the uncertainty of the velocity measurements and increase accuracy of the data. Increased location precision of the measurements will create a more accurate experimental map of the tank that will also correspond better to CFD models. This will allow for the data to map the circulation paths in the tanks and can then be varied to study the effects of inlet configurations on the water circulation as well as different tank shapes.

Experimental Approach

Tank Set up

A square tank with rounded corners was chosen to use for creating the experimental procedure. The tank is made out of fiberglass with gel coating and has dimension of 79" x 79" x 29.5". Previous years projects used a square IBC tote setup, which has wavy, nonuniform surface on the inside and an unsmooth bottom while the inside of the square fiberglass tank is completely smooth. Even though the IBC tote is smaller, the geometry of the fiberglass tank will be easier to model and will lead to less uncertainty for experimentation and CFD modeling. Circular tanks are commonly used for Aquaponic systems due to their excellent self-cleaning and flow patterns that correspond to the tanks shape [3]. The square tank will help to create a precise coordinate system to take experimental data, while having the rounded corners will help mimic the circular flow of a round tank. Square tanks also maximize floor space compared to round tanks.

TABLE 1: FRICTIONAL HEAD LOSSES PER 100 FT. OF 1" SCHEDULE 40 PVC PIPE

GPM	Velocity (fps)	Head Loss (ft)	Head Loss (psi)
2	0.94	0.88	0.38
5	2.34	2.75	1.19
7	3.28	5.04	2.19
10	4.68	9.61	4.16
15	7.01	20.36	8.82
20	9.35	34.68	15.02
25	11.69	25.43	22.7

The pump used to operate the tank will move the water at approximately 20 GPM. A four-inlet design was chosen as the initial experimental setup for water entering the tank through manifolds and it will exit through a single center drain. The PVC pipe diameters were chosen based on expected flow rate through the section of pipe. Using Table 1 to select a pipe diameter that would prevent solid settlements in the pipe and minimize head loss through the length of the pipe. 2" PVC was chosen to connect to the inlet and outlet of the pump, which can be seen in Figure 4. The outlet of the pump led to a 2" PVC ring, constructed to ensure the flow out of each of the inlets is symmetric. Lower volumetric flow rates will be coming out each of the four inlets, so the diameter of the pipe is smaller. 1" diameter pipes will be used for the inlet manifolds to the tank. Reducer tees can be used to connect the 2" ring to the 1" inlets into the tank, as seen in Figure 5. To connect all the PVC, from the pump to the ring to manifolds, proper priming and gluing techniques were used.

FIGURE 4: PVC CONNECTIONS GOING FROM TANK DRAIN TO PUMP INLET, THEN PUMP OUTLET TO PVC RING

Manifold Design

To complete the construction of the inlets of the tank, the manifolds had to be designed. The main design decision was the number of orifices in the length of pipe and their diameter. The head loss out of each inlet is measured in clear manometer tubes attached and it need to be less than 24”. The total orifice area, where the water is flowing out of, is the sum of the area of all the holes in the manifold (equation 1).

$$A_o = \pi \left(\frac{d}{2}\right)^2 (number\ of\ orifices) \ldots\ldots [1]$$

Using the orifice area, the orifice velocity can be calculated using equation 2.

$$v_{avg} = \frac{Q}{A_o} \ldots \ldots [2]$$

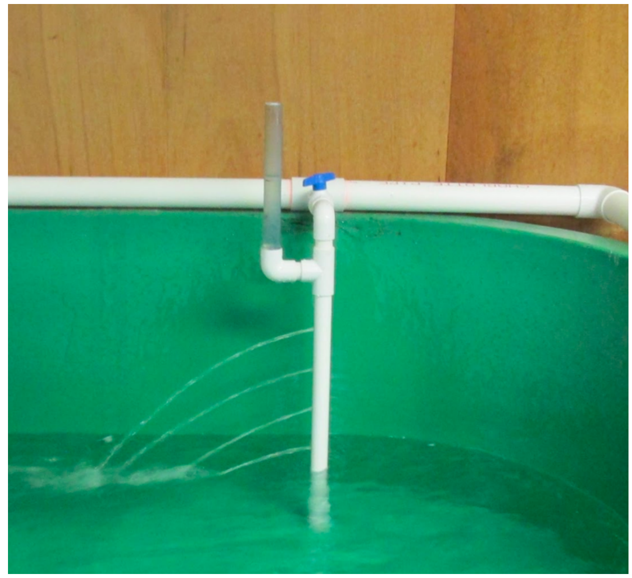


FIGURE 5: MANIFOLD SET UP USED IN THE TANK

The head loss is then related to the volumetric flow rate, Q, and total orifice area, A_e (equation 3).

$$H = \frac{(\frac{Q}{CA_o})^2}{2g} \ldots \ldots [3]$$

The target range for the head loss was between 6-18", after calculating the head loss for a range of orifice sizes and orifice numbers, a design was selected. Seven holes at 5/16" diameter was chosen because it resulted in a calculated head loss of about 11 inches, a value in the middle of the range. 4 identical manifolds were drilled and installed in the fish tank. Figure 5 shows the completed manifold design installed in the tank.

Measurement & Vectrino Mount System Design

In order to develop a repeatable and accurate method to collect data, the way the Vectrino was mounted and positioned throughout the tank needed to be established. There needed to be a structure that would securely support the Vectrino, allow precise placement in the X, Y and Z directions, and be customizable to other tank designs. These requirements resulted in a frame being built around the tank constructed from 8020 Aluminum bars with a cross section area of 1.5” x 1.5”. The material was selected because it was lightweight, easy to obtain, easy to work with and wouldn't corrode. Since it was easy to work with, that meant it could be taken apart and reconfigured for different tanks, while still being stable and secure for data collecting. The frame had dimensions of 90” x 90” x 50”. The frame design was modeled and simulated in SolidWorks (Figure 6) to ensure significant deflection or stress would not alter the structure. The results of the simulation can be seen in Table 2. The final product along with support bars can be seen in Figure 8.

TABLE 2: RESULTS OF SOLIDWORKS SIMULATION ON THE MEASUREMENT SYSTEM DESIGN

Maximum Displacement	Maximum Von Mises Stress Joints	Maximum Von Mises Stress @ Vectrino load	Safety Factor
1.617 mm	.25 MPa	1.26 MPa	32

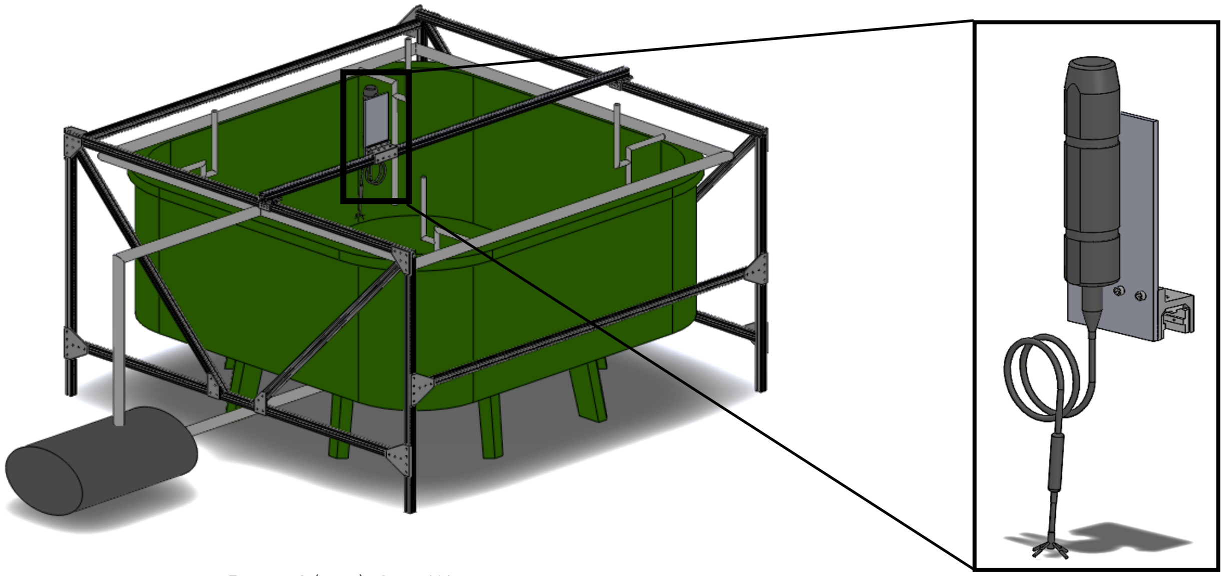


FIGURE 6 (LEFT): SOLIDWORKS MODEL OF THE MEASUREMENT SYSTEM
FIGURE 7 (RIGHT): SOLIDWORKS MODEL OF THE VECTRINO AND VECTRINO MOUNTING PLATE

Another bar ran along the top of the tank, resting on sliders so that it could easily move to different positions in the x-direction. These sliders were loose enough to allow for easy positioning, but they were also fitted enough to prevent them from slipping during testing. The Vectrino housing was attached with hose clamps to an aluminum plate that was secured to another slider so that it could move in the y- direction (Figure 7). Changes in the z-direction were controlled through additional hose clamps on the side of the plate that would hold a threaded rod with the Vectrino probe attached to the end of it in place at various depths. This design provides a more stable support for the Vectrino and makes going to the same test points in the tank much more reliable, which will help reduce the uncertainty in the data. The completed set up is seen below in Figure 8.

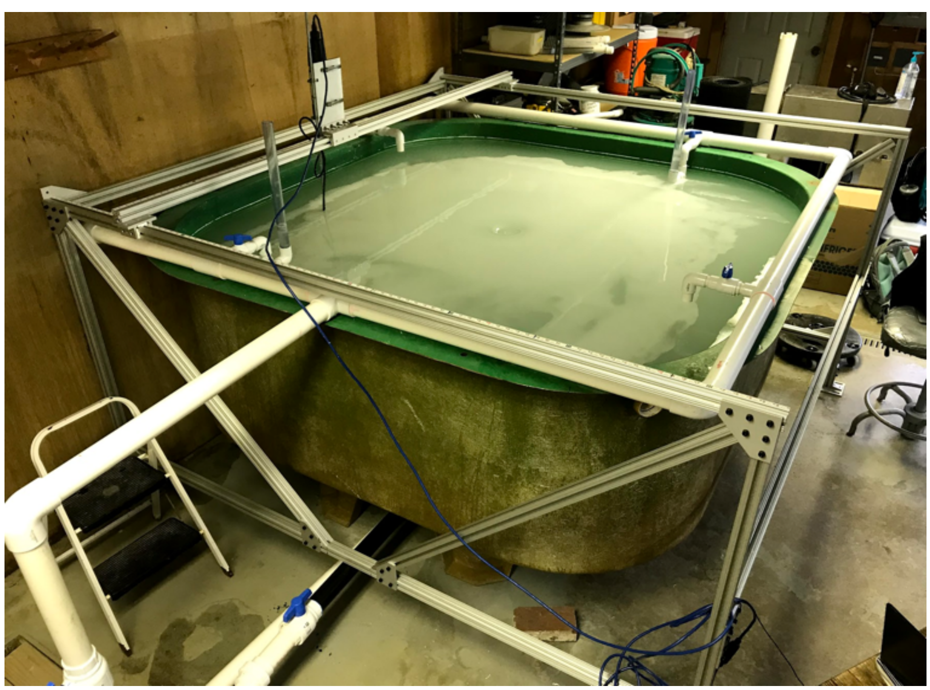


FIGURE 8: MEASUREMENT SYSTEM SETUP

Grid Design

The grid system was defined using adhesive measuring tape placed on the 8020 aluminum bars (Figure 11 and Figure 12). The origin was defined as a corner of the measurement system. On the grid system, it was marked off where the water in the tank is actually positioned, which is different from the zero on the measurement system. From that position on the tape the tank area was divided into symmetric gird points. The complete grid schematic can be seen in Figure 9 and Figure 10. The dimensions of the measured points shown correspond to inches on adhesive measuring tape, while the integers seen opposite represent the naming system used for data collection and in MATLAB. The red points show the points in the complete quadrant used to collect data at each of the three levels. The yellow points show the 3 additional points checked, each at a different level in the other three quadrants, to check for symmetry.

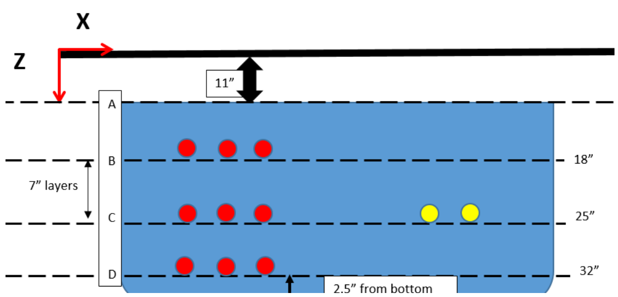


FIGURE 10: EXPERIMENTAL DEPTHS GRID

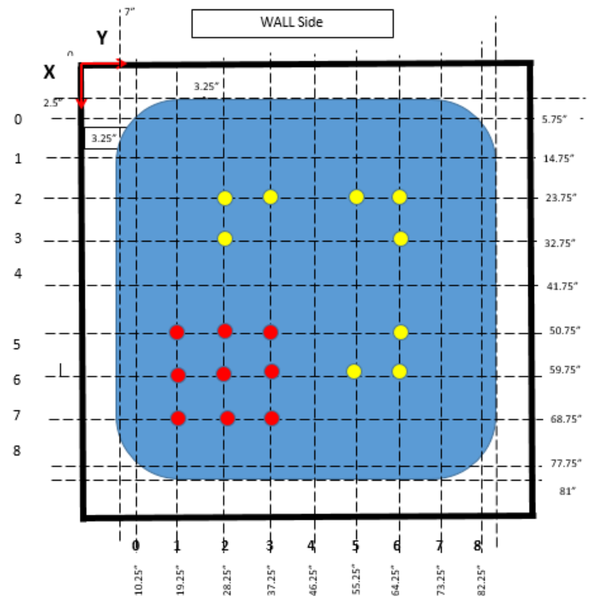
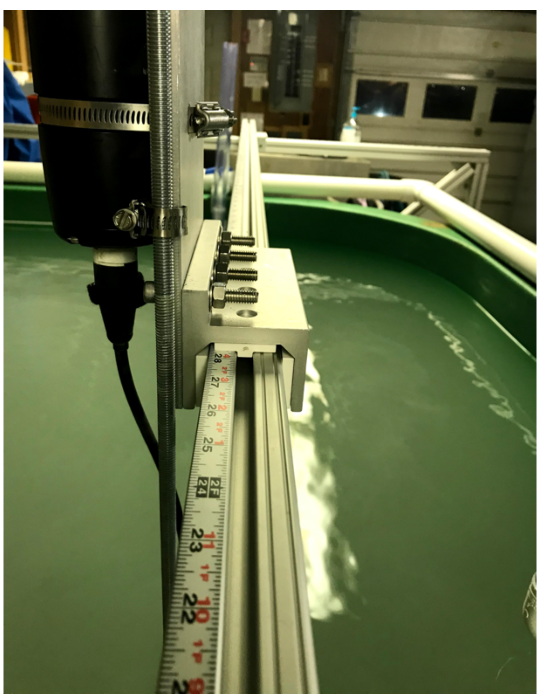


FIGURE 9: HORIZONTAL (XY) MEASUREMENT GRID



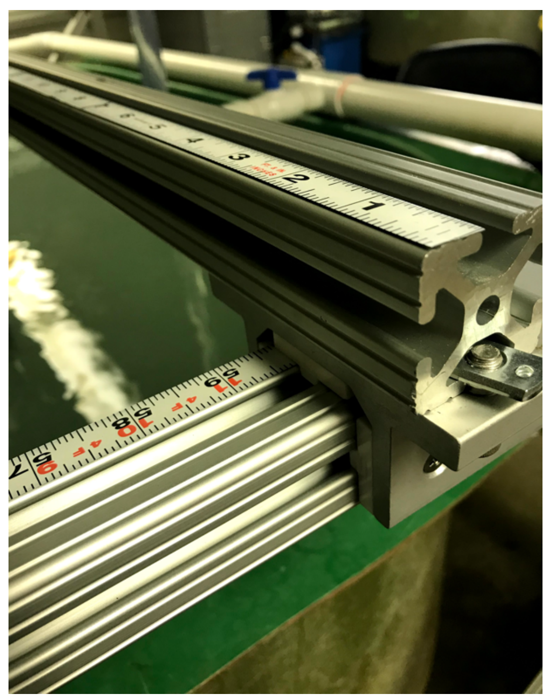


FIGURE 11 (LEFT): CLOSE UP OF THE VECTRINO PLATE MOUNTED TO THE SLIDER AND THE ADHERED MEASURING TAPE USED TO POSITION IT IN THE Y-DIRECTION;
FIGURE 12 (RIGHT) CLOSE UP OF THE CROSS BAR ON THE SLIDER USED TO POSITION THE VECTRINO IN THE X-DIRECTION

Initial Procedure

In order to start collecting data using the Vectrino, the tank needed to be prepared. Tasks included filling tank to appropriate water level, 26" deep just below the manometers, starting the pump and letting it run for at least 15 minutes so the flow can stabilize. The clear manometer tubes are used to ensure the inlet have the same flow rate (1). The flow rate out of each inlet was recorded at 5.5 GPM with head loss of 5" measured from the top of the water. 11 micrometer microspheres were added to the water to improve the signal to noise ratio of the measurements. To complete the setup, the Vectrino subassembly, seen in Figure 13, was placed on the sliding cross bar. To control placement in the Z- direction, an aluminum threaded rod was attached using hose clamps to the plate and the Vectrino probe was then attached to the end of the rod to hold the probe steady while taking data.

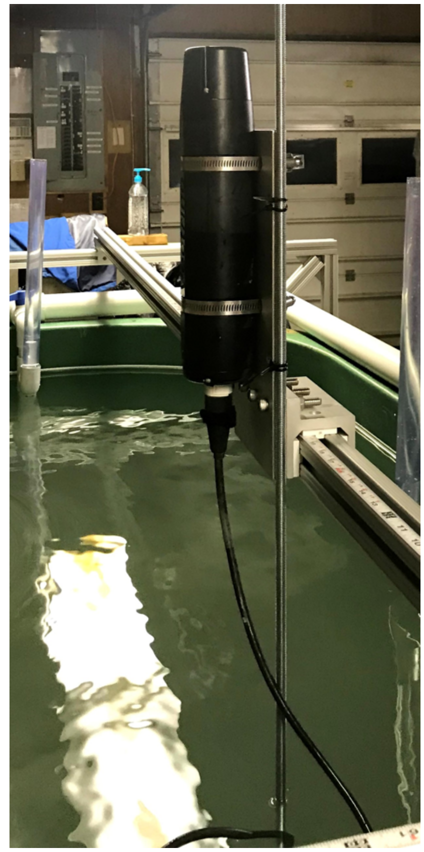


FIGURE 13: VECTRINO MOUNT ON ALUMINUM PLATE

Repeatability Tests

Two different tests were performed to determine accuracy of the experimental setup. First, the length of time necessary for each recording sample. Point 62B (59.75”, 28.25”, -20.5”) was chosen to have the repeatability data taken at it. There were three trials each of 3, 5, 10 and 15 minutes to see how well the running averages compared. The running average is seen in equation 4, when n is the data point being plotted and a_i is the value at the point.

$$m_n = \frac{1}{n}\sum_{i=1}^{n} a_i \dots\dots [4]$$

Through percent error calculations, the time range needed was narrowed down to 5-10 minutes. The 15-minute test didn’t provide much more accurate data than the shorter times, so to allow more data to be collected, the shorter time ranges were observed again. The second set of length of time tests were performed for 5 trials at 5, 7, and 10 minutes.

The second set of the repeatability tests performed involved changing the position of the Vectrino in between each collection then returning it back to its original point to see if the results changed. Knowing how easy it was to disrupt the water flow, it was necessary for the flow to stabilize in between each of the tests. That length of time to allow for the water to stabilize again needed to be determined. More tests were conducted where wait times of 1, 3 and 5 minutes between repositioning the Vectrino to the same point and starting to collect data were used. Each time had 3 trials to further confirm repeatability.

Results

Repeatability Decisions

From taking the tests to determine the time duration data should be recorded for, it was decided that 5 minutes of collecting data would be enough. Figure 14 shows the results for the running average of the x-velocity for each trial of the different lengths of time. The error bars are based on the standard deviation of the average of all the data taken before that point of time. As the time increases in each of the trials, the error bars get smaller, which is what was expected as the more data there is the better the average should be. Focusing at the end time for the test, the error bars are shown to be overlapping on all three lengths of times. Since all lengths of time had about the same overlap in the error bars, it was determined that the 5 minutes of collecting data would be enough for the procedure. Both the y & z directions were also considered in making this decision. While collecting data for longer would provide better data, the differences between the percent errors is minimal since they were all under 2%, as seen in Appendix B (Table 3) and collecting data for less time will allow for more tests to be taken.

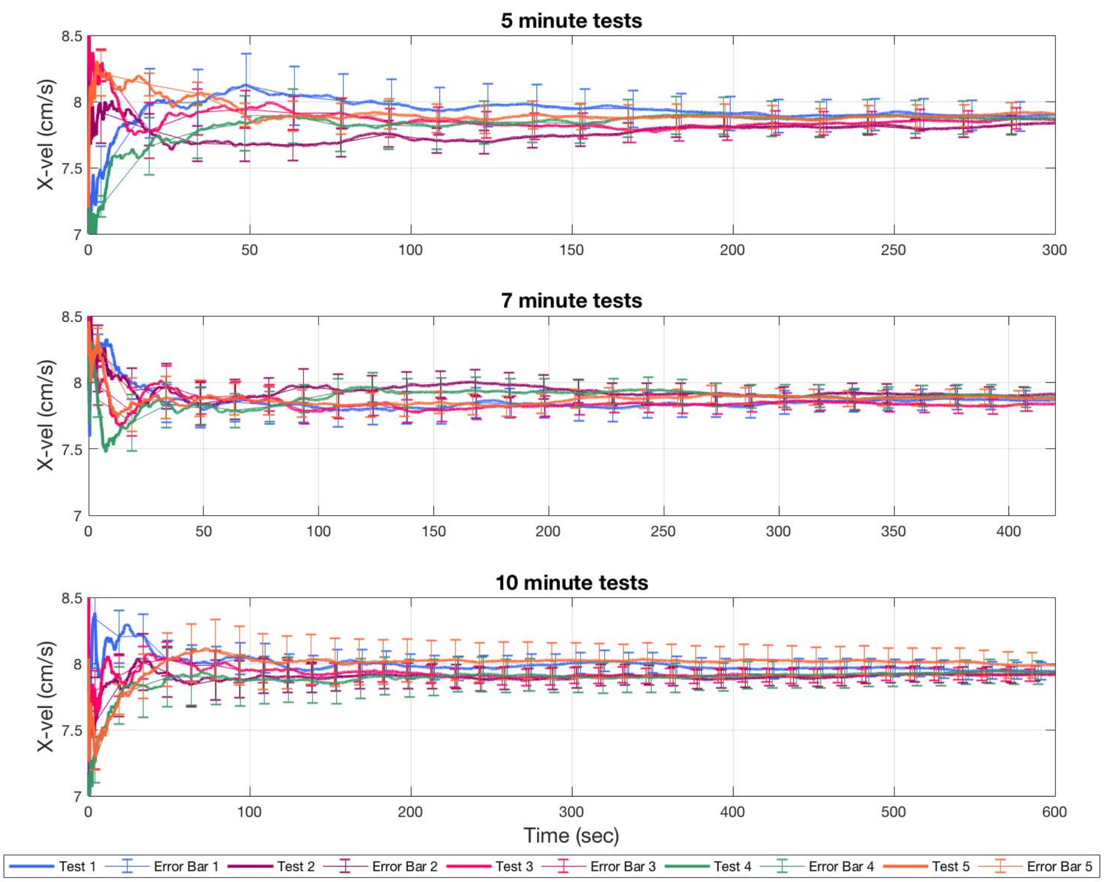


FIGURE 14: RUNNING AVERAGE OF ONE POINT USED TO DETERMINE LENGTH OF TIME NEEDED TO COLLECT ACCURATE DATA

After the 5 minutes was determined to be the length of time for data to be collected, the repeatability had to be confirmed. The measurement system was designed with repeatability in mind, but still needed to be confirmed. While checking the repeatability, how long it would take for the flow to stabilize after movement was also tested. Figure 15 shows the running average plots for the data taken for the 5 trials of each waiting period x- velocities. These plots show two main things, if the data is repeatable and the length of time the flow should be given to re-stabilize. All three plots confirm that the data is repeatable as they average out to roughly the same point. The percent error for these final averages can be seen in Appendix B (Table 4), where all the errors were under 2%. The error bars once again are used to confirm how much the errors overlap at the end, showing if the tests are within the error bars of the others. All three have the error bars overlapping but waiting 3 minutes should be enough. The 5-minute test had an outlying data set, but the percent errors were under 2% for those trials and it was considered acceptable. To help collect more data in the allotted time frame, the shorter time was chosen again, declaring a waiting period of 3 minutes in between tests.

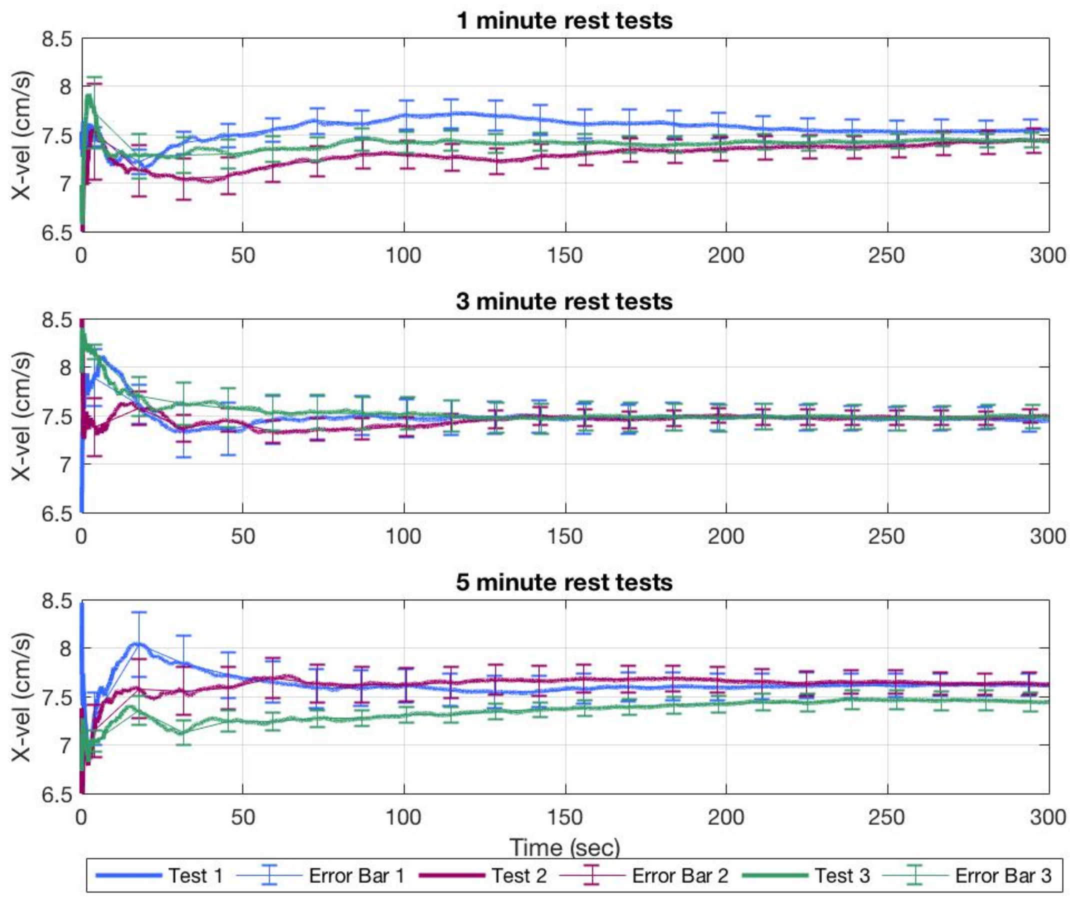


FIGURE 15: RUNNING AVERAGE OF A SINGLE POINT TO DETERMINE REPEATABILITY AND HOW LONG THE FLOW NEEDS TO RESTABILIZE

Final Procedure

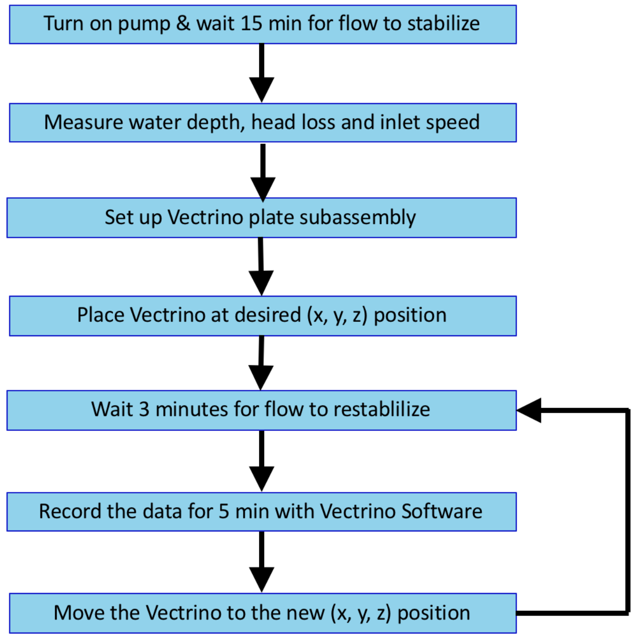


Figure 16: Simplified schematic of the finalized procedure, full procedure in Appendix A

As explained in the initial procure section in experimental approach, the first steps of the procedure were established early on. These steps, including turning the tank on, seeding the tank, measuring the volumetric flow rate, and setting up the Vectrino, needed to be established first so that tests to determine other steps would have a consistent starting point that would not impact those results. The main variables that needed to be determined were how long to collect the data for and how long the Vectrino should sit after being moved before collecting a new set of data. Figure 14 and Figure 15 in the previous section showed how those variables were determined through the experimental testing. The final procedure produced would have the process be to wait for 3 minutes after moving the Vectrino before taking data for 5 minutes. Figure 16 shows a simplified schematic of the final procedure. The first 4 boxes outline the steps that were determined ahead of time and the final three steps were determined experimentally. To continuously take data at different points, the last three steps are repeated as the arrow indicates. A more detailed experimental procedure can be read in Appendix A.

After the data was collected through the Vectrino software and converted to readable files, it could be analyzed a few different ways. As previously seen it could be plotted as a running average to analyze with error bars and percent errors. It also gave a good visualization to how well multiple tests correlated with one another. The other way the data was analyzed was using vector plots, which will be seen later in the report. These provide a good visualization of how the water flow at one point compares to another since it produces a vector that shows the direction of flow at that point and relative magnitude as well.

Configuration Testing

By establishing a complete experimental procedure, now tests could be conducted to map the flow in the tank. Two configurations were chosen for this initial analysis. The first configuration has the four inlets previously described, where water flows parallel to the flat sides of tank in a counter clockwise direction. The second configuration had two inlets open on opposite sides of the tanks with the initial flow the same direction as in the first configuration. These two configurations were used to test the experimental procedure and begin to map the flow at different setups.

Figure 17 and Figure 18 are vector plot of water velocity results from configuration #1. The data collected was based on the grid system described earlier, where one quadrant was mapped with 9 points on three levels and the other quadrants were mapped with only 3 data points to check for symmetry. The exact location of these points can be seen in the grid description. Figure 17 focuses on the one quadrant where the nine data points were taken on three different levels. The vector plot shows that the magnitude of the velocity of the flow remained fairly consistent throughout the tank. The direction however did change at each level and can be seen shifting towards the center of the tank, which is in the top left corner of the plot. The directional change was also greater on the points closer to the edge of the tank, specifically near the corner, which can indicate how the flow performs at the corners.

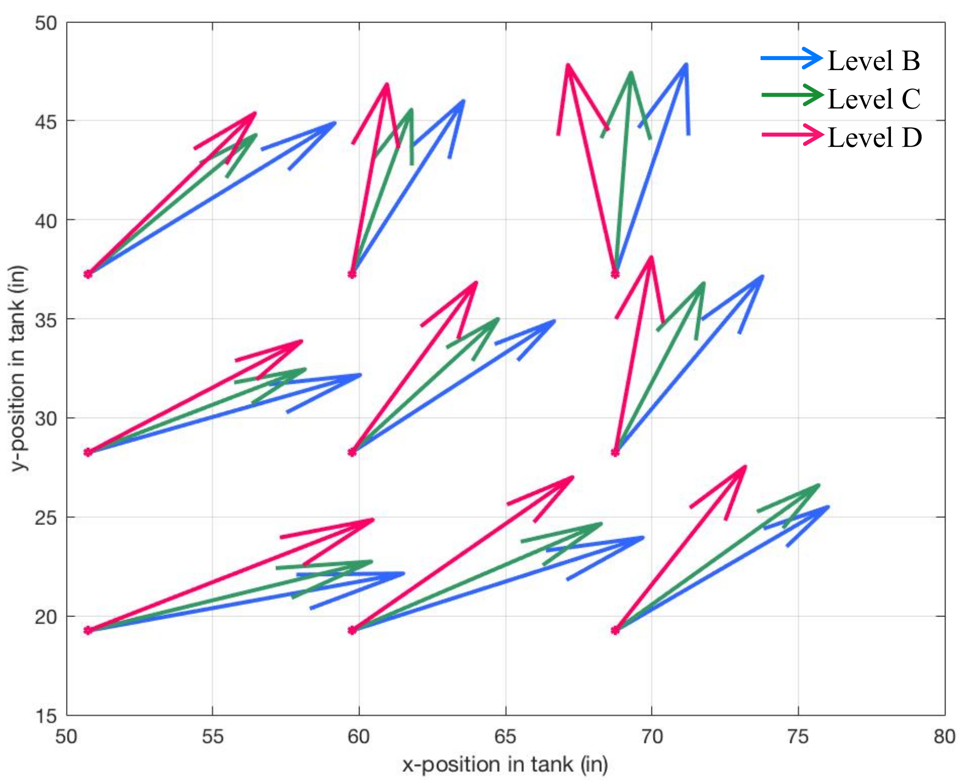


FIGURE 17: VECTOR PLOT OF THE FLOW IN CONFIGURATION #1 FOR ALL LEVELS (B, C, & D) OF THE QUADRANT BEING OBSERVED

Figure 18 shows the vectors of the 4-inlet configuration again, but only for level B. This set of data was collected to check the symmetry of the tank. Since the flow is circular and the inlet is positioned the same in every quadrant, it could be assumed that the flow is symmetric. It was determined that it would be best to confirm that before proceeding with an assumption. From the results in the figure, it is clear that the magnitude of the flow throughout the tank remains the same, confirming that aspect of symmetry. This also verifies the close velocity magnitude seen previously in Figure 17, over all three depths. The direction of the flow however does not look as symmetric as it was thought it would be. There are a few vectors that do not follow the same path and indicate further experimentation should be done to further confirm symmetry.

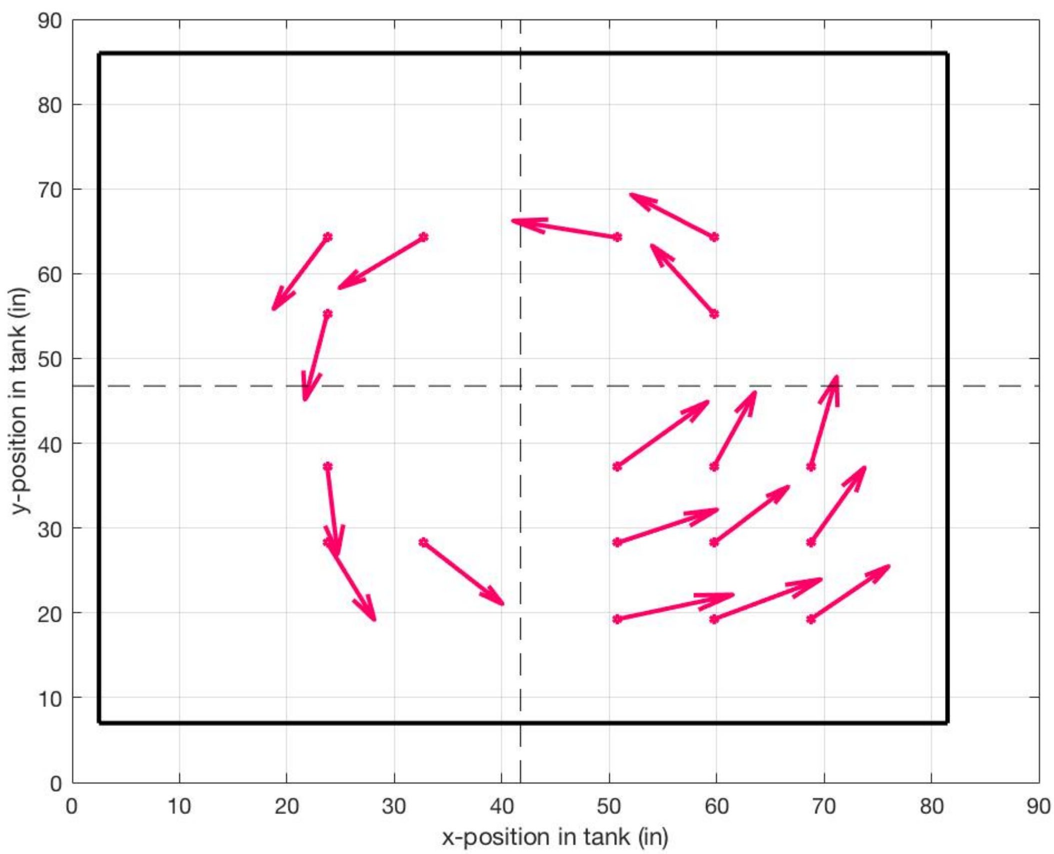


FIGURE 18: VECTOR PLOT OF THE FLOW PATTER IN CONFIGURATION #1 ON LEVEL B; THE POINTS WERE PREDETERMINED BY THE GRID

The two-inlet configuration (configuration #2) can be seen in Figure 19 along with configuration #1 on the B level. The second configuration was measured to start getting an idea of how the inlets effect the flow speed, specifically compared to the flow in the first configuration. The magnitude for the second configuration was a bit slower that the first and moved in a similar pattern. The volumetric flow rates out of the inlets were not significantly changed in the configuration so reducing the number of inlets would slow down water speed. The direction once again needs to be further examined as two quadrants have the direction matching in both configurations while the other two quadrants show the second configuration pointing more towards the center than the first. Further mapping of both configurations should provide a clearer picture of the differences between them.

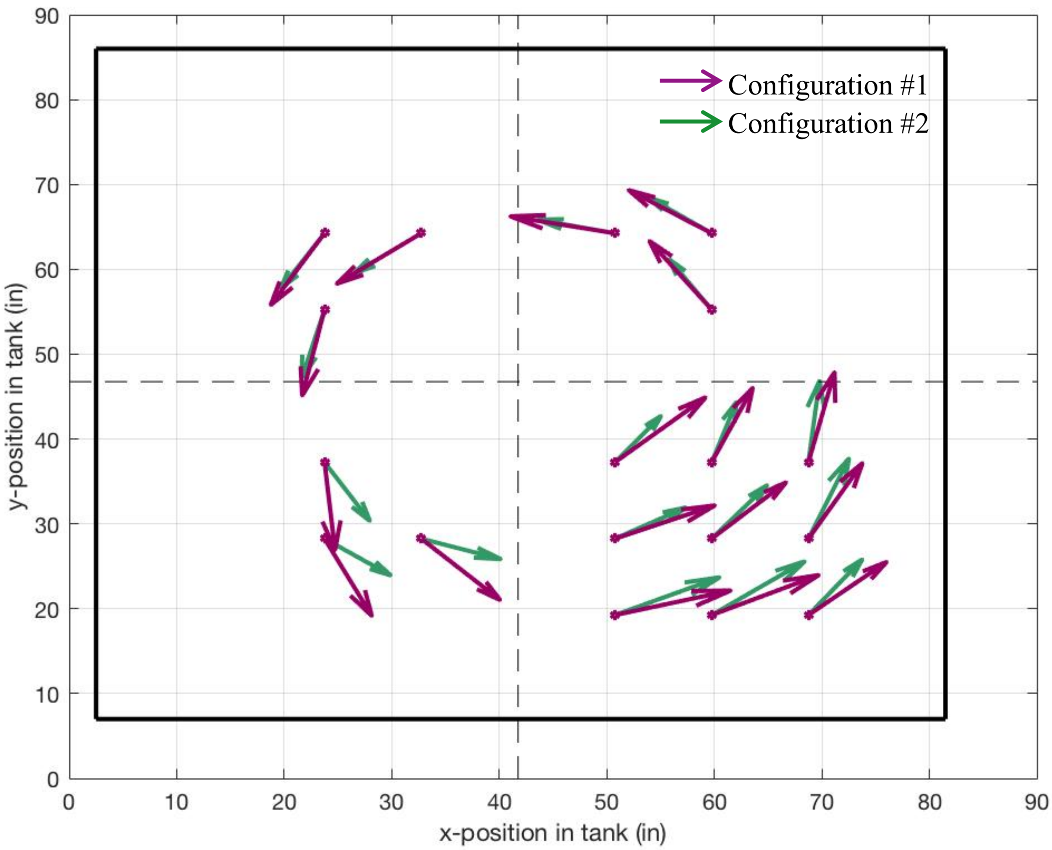


FIGURE 19: VECTOR PLOT OF THE FLOW PATH IN BOTH CONFIGURATIONS #1 & #2, FOCUSING ON THE GRID POINTS ON LEVEL

Conclusions and Discussion

The largest goal this year was to lay the framework for future teams to use to achieve the main goals of the project, designing a more sustainable aquaponics system. By focusing on the experimental procedure and how to collect accurate data, a repeatable method to map the flow in the fish tank has been established. An adjustable frame has been constructed to mount the Vectrino to any location in the tank. The measurement system has the capabilities to accurately position it at a specific point through adhered measuring tape and an established grid system. The frame can be taken apart easily and different sized bars can be added so it can be adaptable on any tank size. A detailed experimental procedure has also been produced to teach future users how to collect data using the measurement and Vectrino mount system. Both have been confirmed to work as data was collected successfully, showing repeatability and low error when these methods were used. The accomplishments from the study this year will allow other groups working on the project to use this established method to collect data to map the tank to better understand the flow experimentally for any tank shape they choose.

Future Work

The next steps for this research project will be to take the measurement system and experimental procedure established this year and use it to analyze other inlet configurations and tank sizes to further understand the circulation paths within them. CFD will also be utilized to correspond the experimental data to the computer data. Ideally, the two should produce the same results after some work has been done. Once additional configurations have been looked at, the project can start to shift towards its central goals, creating an improved design for the tank and lowers the power. After the system has become more cost-effective to install in developing communities, they can start being implemented, beginning with the community in Costa Rica previous research teams have worked with.

Acknowledgements

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Appendix

Appendix A: Full Experimental Procedure

Project OASIS 2018
Experimental Procedure established by Danielle Coombs & Hannah Thomas
Follow this to gather any data that needs to be obtained with the Vectrino in the fish tank

Setting up the tank & Measurement system

1. Turn power on at the circuit breaker between door and garage door. Switch is marked Project OASIS.
2. Make sure that the ball valve on the output of the pump is closed
3. Plug in the pump to the open extension cord by the wall
4. Start to slowly open the ball valve to let water into the plumbing
    a. Turn it about halfway wait for water to start moving
    b. Continue slowly opening it once the water is flowing
    c. This is to prevent the water from overcoming the top of the manometer tubes
5. Once the pump ball valve is completely open, let the tank run for 15 minutes so it reaches a stabilized flow pattern
6. Visually check the manometer to make sure that water is coming out of all manifolds
7. Add about a cup of seeding to the tank
    a. The seeding is the container of 11 micro-meter hollow glass spheres, recommended to use with the Vectrino to boost its signal to noise ratio and also safe for the pump
    b. The water should be murky after adding the seeding, but not totally white
    c. Sometimes you might not have to add more, but in past experiences the old seeding stays on the surface of the water and does not circulate downward where it needs to be
8. Using a tape measure, measure what the current height of the water is in the tank, from the bottom of the tank to the surface of the water
    a. Maintain the same height in between tests
    b. If it is too low add more water via the green garden hose on the other side of the fish barn
9. Using a 5 gallon bucket, time how long it takes for an inlet to reach the lip of the bucket, which marks 5 gallons
    a. Used to determine the volumetric flow rate out of the inlet (GPM)

b. The total volumetric flow rate for the tank is 4 times the one inlet, should match tank pump rate as well
c. Could be done with another sized bucket, just calculate it correctly

10. Once desired flow rate has been reached for one inlet, measured the height of the clear manometer tube to make sure that each inlet is the same
    a. Measure from the water surface to the meniscus of the water in the clear pvc tube (aka manometer)
    b. Head loss is this value
    c. Readjust any inlet that doesn't match the others until the height is the same
11. Take the Vectrino plate off of the bar to attach the Vectrino housing to it
    a. Slide the Vectrino housing up through the hose clamps, so that the chord attaching it to the probe is on the side of the plate with the slider
    b. Line up the divots in the housing with the hose clamps and then tighten the hose clamps with a flat head screwdriver until the Vectrino housing is secured
    c. Keep the foam surrounding the probe on during this process!!
12. Put the Vectrino plate, with the Vectrino attached, back on the sliding cross bar on the side of the tank with the pump
    a. The side of the plate with the Vectrino attached should face the zero-zero coordinate of the x and y bars
    b. This side of the bar will act as the side you use to position with
13. Slide the plate in to the tank, a little bit past the edge
14. Take the threaded rod and slide it through the smaller hose clamps
    a. Use the flat head screwdriver to tighten the rod so that the end of it is about 6 inches above the surface level of the water
15. Take the Vectrino probe out of the foam protection to attach it to the rod
    a. Make sure that the x-axis probe, marked with orange is pointed in the positive x-direction, and that the end of the rod lines up with where the black part of the probe meets the silver rod
    b. Use about 4 smaller zip ties to hold the Vectrino in place
    c. Watch for twisting when tightening the zip ties
16. Attach the blue Vectrino chord to the top of the Vectrino housing into the corresponding holes. Secure it with the black twist collar
17. Plug in the extension cord to the outlet in the rafters near the tank
18. Plug in the Vectrino power source to the end of the extension cord
19. Vectrino software setup (Vectrino plus software previously downloaded to laptop)
    a. Connect blue/white short adapter to long blue vectrino cord, plug USB into laptop
    b. Determine COM port vectrino is connected to
        i. Go to control panel
        ii. Select devices & printers, click on new device that pops up
        iii. Click hardware tab, COM# should be listed there
    c. Open vectrino plus software window
    d. Click communication, select serial port number just found. Baud rate should be set to 9600

e. Click communication connect to connect to vectrino, window should pop-up saying you are now connected. If this doesn't happen, check com port # and baud rate
f. Under file tab, click open configuration and select template used for this project named configuration_template.dep where all the settings should be already setup
g. Check to make sure vectrino is collecting, click collect data icon.
 i. If vectrino probe is in water, curve should be relatively smooth
 ii. If probe still in air, data should be very rigid
h. Set up folders for test data, one for raw data and a separate one for converted data

Running a data collection test

1. While the Vectrino mount is still close to the edge of the tank from previously attaching it, loosen the hose clamps holding the rod in place.
   a. Slide the rod down to the desired height for measurement. The depth is determined from the bottom of the sliding cross bar to the tips of the probes.
   b. Once it is at the right height, tighten the hose clamps to keep the rod in place
   c. Make sure that the probe does not rotate as it moves down
2. Using the sliders, position the Vectrino at the desired x and y coordinate
   a. There is sticky measuring tape adhered to the 8020 bars. Use these to properly position the Vectrino
   b. For the x coordinate, have two people move either end of the sliding cross bar to the position. Have the edge of the bar that faces the origin of the measurement system be the side you line up
   c. For the y coordinate, line up the side of the slider with the rod on it, facing the origin, to the desired measurement point
   d. See grid diagrams for further references for where the origin is and where points are measured from specifically
3. Once the vectrino is in the desired position, wait 3 minutes for the flow to stabilize around it
4. While waiting, rename the file you are saving to on the vectrino software
   a. The current naming system is dependent on the original grid, but can be easily adjusted to meet your needs
   b. Vec_xyz_testn
5. After the three minutes are up, start a new timer for 5 minutes and begin recording data on the vectrino software
6. After the 5 minutes, stop recording data and save the file
7. Move the vectrino to a new point by repeating step 2
   a. If the z direction is changing, bring the vectrino to the edge of the tank and repeat step 1
8. To record more data, repeat steps 3-7 until all the data has been collected
9. Once all data is collected, convert the vectrino data to .dat files to be read into matlab later
   a. Can do this using vectrino software
   b. Click data conversion icon, select list of files you want to convert (Raw data folder)
   c. Select folder you want them to save in (converted data folder)

d. Click select all, then blue arrow to convert
e. Make sure header, velocity, amplitude and sensors boxes are checked off then click ok

10. Take everything apart by undoing how it was put together
    a. Once the vectrino probe is off the rod, replace the foam cover to prevent damage; damages=$$$$$
    b. Turn off Project OASIS circuit breaker by door before leaving

Appendix B: Additional Figures and Tables

TABLE 3: X-VELOCITY PERCENT ERROR TABLE FOR THE TEST TIME REPEATABILITY TESTS

	velocity (cm/s)	% error local	%error overall
5 min –test 1	7.901	0.53 %	0.00 %
5 min –test 2	7.837	0.30 %	0.82 %
5 min –test 3	7.860	0.00 %	0.53 %
5 min –test 4	7.872	0.16 %	0.37 %
5 min –test 5	7.905	0.57 %	0.04 %
5 min-overall	7.860	---	0.52 %
7 min –test 1	7.868	0.12 %	0.43 %
7 min –test 2	7.912	0.44 %	0.13 %
7 min –test 3	7.838	0.50 %	0.81 %
7 min –test 4	7.890	0.16 %	0.14 %
7 min –test 5	7.877	0.00 %	0.31 %
7 min-overall	7.877	---	0.30 %
10 min-test 1	7.940	0.00 %	0.48 %
10 min-test 2	7.922	0.22 %	0.26 %
10 min-test 3	7.916	0.30 %	0.18 %
10 min-test 4	7.937	0.03 %	0.45 %
10 min-test 5	7.987	0.60 %	1.08 %
10 min-overall	7.939	---	0.01%
Overall avg	7.902	---	---

TABLE 4: X-VELOCITY PERCENT ERROR TABLE FOR THE WAIT TIME REPEATABILITY TESTS (2)

	velocity (cm/s)	% error local	%error overall
1 min –test 1	7.547	1.76 %	0.90 %
1 min –test 2	7.439	0.31 %	0.55 %
1 min –test 3	7.430	0.19 %	0.67 %
1 min-overall	7.416	---	0.86 %
3 min –test 1	7.446	0.59 %	0.45 %
3 min –test 2	7.495	0.07 %	0.20 %
3 min –test 3	7.480	0.13 %	0.00 %
3 min-overall	7.490	---	0.13 %
5 min-test 1	7.613	1.05 %	1.77 %
5 min-test 2	7.623	1.18 %	1.91 %
5 min-test 3	7.442	1.22 %	0.51 %
5 min-overall	7.534	---	0.72 %
Overall avg	7.480	---	---