Method for a Low Cost Hydrokinetic Test Platform: An Open Source Water Flume

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Abstract

While educational wind tunnels are common place for instruction and experiments in fluid mechanics, they generally do not possess the capabilities to perform hydrodynamic testing. This paper will present the work by the authors to develop a water flume that would allow hydrodynamic testing at velocities up to 2.0 m/s. The flume was constructed by an undergraduate and at a cost lower than commonly available commercial units. Both the fabrication process and the potential experiments that the flume could house are designed to improve student learning in the area of fluid mechanics. The design is developed to be relatively compact, with a 7’ x 3.5’ footprint and utilizes a commonly available single-stage centrifugal pump. Flow velocities in the test section can be varied passively by changing the insert containing the test section and actively with a recirculation valve. The total cost for this project was approximately $3500 and required 3 months of part-time work to construct. Flow velocity measurements in the test section were made by simple flow visualization and found velocity ranged from 0.32-0.65 ft/s within a 6” x 12” x 12” test section. The water flume was subsequently used by a senior capstone project for testing of their water turbine. Student self-evaluations were used to assess whether their experiences reinforced fluid mechanics concepts and developed their skills in experimental fluid mechanics. The results show that the students believed their work with the water tunnel strongly met the learning objectives in the area of experimental methods and somewhat met in the area of concepts. Although the data set was small (5 students), it does show promising correlations that highlight the potential of the water flume in an engineering educational environment.

Introduction

Fluid mechanics is a fundamental engineering concept that is taught in the classroom and reinforced through experiments and demonstrations. The latter provide physical evidence for concepts introduced in lecture and better appeals to the students’ intuition. At California State University, Maritime Academy (CSUM), the bulk of the fluid mechanics demonstrations and experiments are conducted in the university’s Aerolab Educational Wind Tunnel. The wind tunnel has a 12” x 12” x 24” test section and is capable of air velocities of 40 mph – 140 mph. However, the wind tunnel does have its limitations. The velocity range means test objects sized for the wind tunnel will have Reynolds Numbers on the order of $10^5$ or larger.
An alternative test platform that addresses this limitation would be a water flume. A water flume is essentially a rectangular channel through which water flows at a controlled velocity. The top of the channel is a free surface exposed to atmospheric conditions. A test object can be either submerged in the water or placed on the free surface. This makes the water flume better suited for experiments such as the simulation of river and ocean flow or the testing of hydrofoils and ship hulls. In particular, there is a need for simulating hydraulic environments at institutions where there is strong interest in maritime engineering and marine science, such as the CSUM. Although testing could be carried out in the adjoining Carquinez Strait or San Pablo Bay, there is a need for a controlled test environment for educational and testing purposes. This would allow students in courses such as Naval Architecture and Marine Science to have an experimental setup where they could visualize and measure the effects of low velocity water flows on their field of study.

Instructors have demonstrated the clear value of supplementing fluid mechanics theory with flow visualization. For example, Crimaldi et al. [1] examined the correlation between student learning and student demonstrations of planar laser induced fluorescence for turbulent flow visualization in a water flume. That study found that the demonstrations generally improved exam performance. In the wind tunnel, the primary means of flow visualization is the use of commercially available smoke generators in conjunction with either smoke wands or smoke rakes, such as the one developed by Beck et al. [2] Commercially available smoke generation systems are generally cost prohibitive. In addition, the use of smoke in CSUM’s wind tunnel is limited due to the poor ventilation in the laboratory space. Flow visualization in water flume may be easier to achieve in this environment. Dye injection in water achieves many of the same objectives without the need for a smoke generator. There is greater control of the injection flow rate, which alleviates some of the problems associated with dissipation. More advanced fluid measurement methods such as Doppler velocimetry or particle image velocimetry would be easier to introduce in the water as compared to air.

The challenge is that water flumes can be costly and require large laboratory spaces, making them rare at small to medium size universities. The model shown in Figure 1 is a research water flume with controlled flow velocities of 0.1-1.7 ft/s, a 20” x 20” test cross-section, and a total length of 8’-20’. This is well suited for experiments simulating conditions in river environments. However, generally, commercially available water flumes cost approximately $20,000 to $30,000. [3] This prohibitive cost has led educators to explore alternatives. For example, Forringer, et al. [4] built a “Low Cost River Simulator” for an undergraduate project testing a small hydrokinetic generator designed for river flows. They used a trolling motor to drive a low velocity water flow around a 24’ diameter pool. The setup achieved flows of 2 mph-
4.5 mph at a cost of $500 for the equipment added onto the pre-existing pool. While this type of setup produced acceptable results, it would be a challenge to implement in laboratories that are space constrained, such as CSUM.

Figure 1: An image of an “artificial river” water flume manufactured by Aquabiotech. [5]

The overall goal of this work is to present a cost effective, closed-loop water flume capable of simulating the low velocity flow conditions seen in tides and rivers. This water flume was first proposed to serve as an experimental setup for a senior capstone project studying a low velocity water turbine. However, it grew into the development of a setup that could be used regularly for fluid mechanics experiments and demonstrations. The water flume would allow for testing at lower Reynolds Numbers and the introduction of flow visualization. The water flume would provide basic testing facilities which, although not directly comparable in capability, would only require a fraction of the resources of a commercially available water flume and could be constructed by an undergraduate student.

**Design**

As described in the introduction, a water flume is a system that circulates water in a single direction at repeatable, variable flow velocities. With that goal in mind, the next step was to define the requirements that would define a successful water flume design. The following objectives were identified at the outset of the project:
A. The construction costs should be less than $3500.
B. The construction can be carried out by undergraduate.
C. The water flume will provide “low velocity” flow-rates up to 2 ft/s in the test section to replicate tidal and river flows.
D. The water flume will fit in a laboratory with limited space. For this particular laboratory, this meant a maximum 7’ x 7’ footprint and having the ability to relocate the experiment easily.

The basic layout of the resulting design is shown in Figure 2. Each of the key components will be briefly introduced, while a full discussion follows in their own subsection. All experiments take place in the inside of the testing tank. To tailor the flow to needs of the experiment, a removable insert is placed inside the testing tank. The water flow is driven through the entire water flume by a centrifugal pump. The water is injected into the testing tank by the flow source. Water is drawn back into the piping system via the flow sink located at the rear of the testing tank. For this water flume, an optional holding tank was plumbed to allow for the long-term storage of the water outside of the testing tank.

Figure 2: A simplified schematic of the water flume setup. The flow within the testing tank goes from the left to the right, as illustrated by the blue arrow. Testing occurs within the center of the insert (gray) where test section is located. The components labeled in italics are for the optional holding tank.
Testing Tank. The testing tank is essentially an open top rectangular tank. For this water flume, the testing tank is constructed out of 1/2” thick transparent aquarium grade acrylic. Acrylic was the logical choice of material given its strength, optical transparency, cost, and ability to be worked into a water tight structure. As seen in Figure 3, the interior of the tank measures 72” long (axial direction), 12” wide, and 18” high. The dimensions were developed based on the size constraints and the support structure. The design of the testing tank was done with extensive input from the manufacturer, Kritter Tanks. The two flanges, 3” wide, that can be seen running axially along the top of both sides of the tank were added for stiffness. The flanges have the added benefit of acting as a structure on which instrumentation can be attached. Two holes, 1.5” in diameter are drilled into the bottom and located 6” from either end wall of the tank. The holes are sized to accommodate the installation of a through wall bulkhead pipe fitting. The fitting serves as the connection between the plumbing underneath and the flow source and flow sink plumbing within the testing tank.

Figure 3: A 3-D isometric rendering of the testing tank (a) and a simplified drawing of the interior of the testing tank as seen from above (b) and from the side (c).

Removable Testing Tank Insert. It was decided initially that the flow would need to resemble the flow in a wind tunnel. This meant that the water would go through an upstream converging section, a constant area test section, and a diverging section downwind section. This led to the design of a removable testing tank insert, hereafter referred to as the insert. The motivation for a removable nature of the insert was to provide flexibility by allowing different width test sections based on the experiment’s size and velocity requirements. A simplified drawing of the interior volume of the insert is shown in
Figure 4, including dimensions of the central test section. The walls of the current insert are made of polyethylene sheets that are cut to the appropriate geometry and secured to a rectangular base sheet of polyethylene that spans the bottom of the testing tank. Attachments between the sheets and to the base were made by the use of regularly spaced stainless screws. Cutouts were made to avoid interfering with the wall bulkhead fittings mounted at the base of the testing tank. Pictures of the current insert are shown in Figure 5 and Figure 6.

Figure 4: A simplified engineering drawing of the interior of the insert. The drawings above are top views, while the drawings on the bottom are the side profiles. The dimensions of the test section are shown in the upper figure.
Figure 5: A photograph from the current insert as seen from above, where the fluid flows from the left to the right. This insert was used for the work discussed in this paper. The test section can be seen in the center. A permanent insert will be constructed from transparent acrylic to allow visual access.

![Figure 5: A photograph from the current insert as seen from above, where the fluid flows from the left to the right. This insert was used for the work discussed in this paper. The test section can be seen in the center. A permanent insert will be constructed from transparent acrylic to allow visual access.](image)

Figure 6: A photograph of the insert looking downstream from the front of the tank. The flow straightener (white plastic grid) can be seen in the foreground, followed by the contraction and test section behind it.

As seen in

Figure 5, the flow enters the insert through the plastic flow straightener, which is approximately 1” thick and has a regular square pattern as seen in

Figure 6. This flow straightener is used to help reduce the non-axial velocity components in the flow. The converging section acts to accelerate the flow prior to the test section. The test section width acts as a passive velocity control since, for a constant flow rate from the pump, the velocity and area are inversely related by the conservation of mass for an incompressible flow [6]:

$$\dot{m} = \rho U A$$  \hspace{1cm} [1]

where:

\(\dot{m}\) is the mass flow rate in lbm/s,
\(\rho\) is the density in lbm/ft\(^3\),
\(U\) is the flow velocity in ft/s, and
\(A\) is the cross-sectional area in ft\(^2\).
The test section for this insert measures 6” wide and 18” long and is located in the center as seen in Figure 4. Upon passing through the test section, the flow then decelerates in the diverging section before leaving through the flow sink. The fact that the insert is removable means that it can be interchanged with another insert geometry that may favor width over velocity or contains experiment specific hardware.

The version of the insert presented is the first iteration prototype. The purpose of the prototype was to make the initial assessments and assess the flow behavior. The next version of the insert, to be fabricated in the summer of 2017, will consist of acrylic to provide optical access throughout the test section. This will be critical for the implementation of flow visualization experiments. The acrylic version will be glued at fabrication rather than attached by screws. In addition, the next iteration will have a longer flow straightener with smaller sized passages further reduce the non-axial velocity components in the flow.

**Pump.** The flow through the entire setup is powered by a Dayton 2HP centrifugal pump. This particular pump was selected based on cost and availability. The rated output of 94 gpm at 10’ of head meant that velocities in the test section should be approximately 0.5 ft/s. During the design process, this was deemed sufficient, with some margin stemming from the expected head losses, which were lower than 10’. Although this would be short of the initial objectives for flow velocity, it was the best balance between the performance and budgetary objectives.

Ideally, the flow rate out of the pump would be controlled by a variable frequency drive (VFD). Unfortunately, the cost of the VFD would have caused the budget to far exceed the objective. Instead, to vary the flow velocity, a bypass valve was installed in a recirculation path from the discharge side of the pump to the suction side of the pump. By opening or closing the valve, the mass flow rate going into the testing tank could be varied. The bypass valve selected was a brass butterfly valve, which provided acceptable control with minimal pressure losses. The use of a globe or throttling valve would provide more control but would have put the design over budget. A photograph of the pump, valve, and adjoining pipes are shown in Figure 7.
Figure 7: A photograph of the plumbing underneath the front of the testing tank. The pump (lower left) moves water upward to the tank. The bypass valve (center, bronze) allows for some of the flow to recirculate, thereby creating controlled variability in the flow rate through the testing tank.

*Flow Source and Flow Sink.* The components that went through the most redesign during development were the flow source, which would supply the water flow into the testing tank, and the flow sink, which would draw the water out of the testing tank. The challenge was finding geometries for the flow source and the flow sink that delivered the most uniform velocity profile in the test section and minimized both pressure losses and splashing of water over the walls of the tank.

Initially, computational fluid dynamics (CFD) was used to establish a basic design for the flow source and the flow sink. The primary goal was to verify that the expected flow through the test section would be relatively axial. Simulations were carried out in ANSYS CFX. In the simulations, the fluid was assumed to be incompressible water at standard temperature and pressure. The flow rates were based on the expected performance of the pump, based on manufacturer documentation. A $k$-$\varepsilon$ turbulence model and atmospheric pressure boundary condition were applied. However, the lack of a deformable free surface meant that waves and splashing would not be captured. The loss in accuracy was needed given the limited computing
power available for the simulations. During post-processing, streamlines and velocity profiles were examined and used to assist in deciding the next iteration of design changes.

The CFD simulations found that a flow source that consisted of a simple capped 2” diameter pipe with a 1” high, 1.5” wide rectangular cutout (Figure 8a) facing the forward testing tank wall would acceptably disperse the flow, creating flow through the test section that was relatively axial. A sample of the post-processed results on which this assessment was based can be seen in Figure 9. However, upon testing in the actual setup, it was found that flow source as designed created a jet that was too concentrated. It had issues with splashing and created high velocity flow only in the center. The decision was made to break up the single outlet into multiple outlets to help distribute the flow throughout the cross section. That led to the development of a second design (Figure 8b). This design was found to reduce splashing. However, the smaller 1” diameter outlets created localized jets with noticeably higher velocities at the lower outlets. The final iteration (Figure 8c) was found to have the best performance. The larger but fewer 1.5” diameter outlets had slower outlet jets and did not suffer from the same velocity variations between the upper and lower outlets. This led to a more uniform velocity profile in the test section that would be qualitatively verified by tuft testing. A photograph of the source currently installed on the water flume can be seen in Figure 10.
Figure 8: Images of the evolution of the flow source design. All versions would have their outlets pointed upstream toward the wall to disperse the flow and breakup the jets that would form upon exit. The simple pipe version (a) was derived from CFD simulations. Based testing, the flow source evolved to a more complex tree of outlets (b), before finally settling on the final design (c).

Figure 9: Post-processed results from the CFD simulation of where the flow source and flow sink use the same single capped pipe with rectangular cut-out, as seen in Figure 8a. Streamlines are rendered as seen from the above (top) and the side (bottom).
Figure 10: Photograph of the installed flow source. Note that the outlets point upstream toward the forward wall of the testing tank to break up the jets that form upon exit. The flow then turns downstream toward the flow straightener.

The flow sink underwent a similar revision. In the CFD simulations, the original design for the flow sink was the same as the initial design of the flow source (Figure 8a). However, upon testing, it became evident that geometry was favoring faster flows near the center of the cross section, while causing distinct recirculation regions throughout the rear of the testing tank. This led to a handful of iterations of the flow sink design. Ultimately, the final design utilized a tee whose horizontal axis is perpendicular to the flow as seen in Figure 11. This design created the least amount of variation in the axial velocity in the test section.
Figure 11: Final flow sink design as viewed from (a) above and from (b) the rear of the testing tank looking upstream. In the view from above, the flow comes in from the left as indicated by the light blue arrow. Note that the inlet pipe is perpendicular to the oncoming flow.

Support Structure. The support structure needed to meet the following requirements: a) the ability to support the weight of the fluid (approximately 600 lbf), pump, and other hardware, b) the ability to dampen vibrations produced by the pump, and c) the ability to be moved easily. For this water flume, a commercially available laboratory bench made of low carbon steel and measuring 7’ long, 4’ wide, and 4’ high was modified for use as the support structure. The bench was modified to include two levels: an upper level used to support the water flume and a lower level used to support the storage tank, pump, valves, and piping. Rubber dampers were installed on the pump mounts to reduce the transmission of vibrations produced by the pump. High strength locking castors were installed at each base to allow for water flume to be rolled within the laboratory. All of the water flume’s components were securely mounted to the structure to prevent shifting during transport.

Construction

This section highlights some of the observations and challenges associated with the construction of the water flume. In no way is this intended to be a full construction methodology and caution should be used during the construction process. A key step in the development process is reaching out and collaborating with a local aquarium or plastics manufacturer capable of fabricating the testing tank. This is critical in ensuring the proper manufacturing of the testing tank and minimizing the possibility of a leak or a structural failure in the future. For this water flume, the manufacturer was critical in identifying potential problems and weaknesses in the early designs of the testing tank and the removable insert. Upon finalization of the design, the
vendor provided full construction and delivery of the fabricated components. While the goal was to have the water flume constructed entirely by an undergraduate, a manufacturer with experience with acrylic tanks is required in the testing tank fabrication to avoid major setbacks.

The major consideration regarding the construction process is the assembly of the plumbing. The project almost entirely uses PVC schedule 40 pipe. The majority of the plumbing uses 2” diameter pipe. These pipes are larger than either of the fittings on the pump (the inlet and outlet pipe sizes for this pump were 1.5” and 1.75” respectively) and were selected to reduce pressure losses. The PVC pipes and fittings were all commonly available from major hardware retail outlets. It is important that any undergraduates trying to replicate this work be aware of proper procedures when working with PVC plumbing, and in particular the selection of components (including unions to help with the assembly and disassembly of sections of piping), the measurement of the piping, and the cementing of PVC components.

A consideration that should be addressed in the design process and carefully implemented in the construction process is the connection of the plumbing to the testing tank. This is accomplished through the installation of two threaded wall bulkheads mounted at the bottom of the testing tank. The holes in the testing tank for these bulkheads can be seen in Figure 3a. The holes through the upper surface of the support structure must be clearance holes that allow at a minimum the widest part of the bulkhead to pass through. This is required to ensure that the testing tank lies flush with the support structure’s surface. However, the hole should be drilled slightly larger to allow tool access during tightening. These bulkheads must be tightened to specification to ensure a water tight seal. This installation should occur before any of the other plumbing is installed. The bulkheads provide threaded female connections for 2” threaded fittings on either side, allowing for the connection to the plumbing underneath and attachment of the flow source and flow sink above. The forward bulkhead can be seen at the front of the testing tank in black just below the waterline in Figure 12.
Figure 12: A photograph of the water flume with all of the components except the removable insert installed.

A budget is Table 1 to help with estimating costs to replicate the water flume. Along with costs, the particular part numbers and manufacturers of the major components are provided as well. As mentioned previously, the holding tank was installed to store the water when the flume was not in use, reducing contamination and potential risk to the other experiments around it. If this option is not needed, then the final budget comes close to the budget of $3500 laid out in the objectives.

Table 1: A bill of materials providing details of the major components used and a budget breakdown.

<table>
<thead>
<tr>
<th>Component</th>
<th>Manufacturer</th>
<th>Item Number</th>
<th>Cost (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centrifugal Pump</td>
<td>Dayton</td>
<td>2ZXP6</td>
<td>$807</td>
</tr>
<tr>
<td>Water Flume Structure &amp; Insert</td>
<td>Kritter Tanks*</td>
<td>N/A</td>
<td>$1,850</td>
</tr>
<tr>
<td>Holding Tank</td>
<td>McMaster-Carr</td>
<td>5152T42</td>
<td>$265</td>
</tr>
<tr>
<td>Support Structure</td>
<td>Various</td>
<td>N/A</td>
<td>$500</td>
</tr>
<tr>
<td>PVC Schedule 40 Piping</td>
<td>Various</td>
<td>N/A</td>
<td>$250</td>
</tr>
<tr>
<td>Bypass Valve</td>
<td>McMaster-Carr</td>
<td>4682K59</td>
<td>$72</td>
</tr>
<tr>
<td>Miscellaneous Hardware</td>
<td>N/A</td>
<td>N/A</td>
<td>$75</td>
</tr>
</tbody>
</table>

| Total Cost with Holding Tank       | $3,819             |
| Total Cost without Holding Tank    | $3,554             |

*Contact Information: Gen Wata, gen@krittertanks.com
Results

The testing of the completed water flume involved measuring flow velocities and flow patterns within the test section at different settings of the bypass valve. To quantify the flow, local velocity measurements were made using a simple form of flow visualization. Small neutrally buoyant spheres (HDPE Polyethylene) were used with a camera of known frame rate to measure velocities in the test section. Optical distortions were corrected by capturing images over the test section of an immersed ruler at different depths. This provided the spatial calibration. The particles were released into the flow and images were captured as it traversed along the tunnel. The travel distance in pixels was measured between images. Using the calibration data and the known frame rate of camera (10 frames per second), local velocities could be derived from the data.

Two to three measurements were made at different locations in the test section to help quantify the velocity profile. The tank was filled to a height of 15”. Flow velocity was measured at three different settings of the bypass valve: 100% open (slowest flow), 50% open, and 0% open (fastest flow, no bypass). The mean velocities in the test section are shown in Table 2. The results agree with the initial predictions from the pump sizing. Although this water flume does replicate low velocity flow, unfortunately, it did not meet the full range laid out in the initial objectives. The maximum velocity of 0.652 ft/s is short of the 2 ft/s desired. The simplest solution to remedy this would be the installation of a pump capable of more displacement, although that will alter the budget as well. If it is tolerable for the designated experiment, it is possible to use a different removable insert with a smaller test section width and/or lower water level height.

Table 2: Average flow velocity within the test section based on flow visualization measurements.

<table>
<thead>
<tr>
<th>Recirculation Valve % Open</th>
<th>Average Velocity (ft/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.652</td>
</tr>
<tr>
<td>50</td>
<td>0.475</td>
</tr>
<tr>
<td>100</td>
<td>0.327</td>
</tr>
</tbody>
</table>

An attempt was made to characterize the variation in the axial flow profile in the test section through the development of a pitot tube connected to a dry differential pressure transducer. However, from the onset, there were problems getting reliable measurements. The source of the
error was found to be due to the interaction between the fluid in the pitot tube and the air in the tubing leading to the transducer. This inaccuracy is predominantly driven by the surface tension and viscosity of the water in the pitot tube and has been examined in previous research. [7,8] Three separate pitot tube designs were tested in an attempt to rectify the problem; however, none were successful. Investigating this problem led to the determination that a wet/wet differential pressure transducer for low pressure differentials would be needed. However, it was found that each transducer would cost approximately $1500, exceeding the project’s operating budget. This idea has been tabled until funding can be secured.

For future Fluid/Thermal Lab courses, modifications will be need to be implemented. As mentioned previously, the finalized version of the acrylic insert will be used to provide complete optical access of the test section. In addition, more supporting instrumentation will be created. Development of alternative velocity instrumentation will need to be carried out. Another goal is to develop a simple flow visualization setup through the use of dye and a planar light source. These improvements will allow the water flume to supplement experiments currently run in the wind tunnel, such as the study of drag on a sphere or forces on an airfoil.

However, the water flume has still found an academic application in its current state. A senior capstone project group is using the water flume to test a low velocity water turbine designed to utilize the currents associated with the changing tides. The project’s core concept comes from the study of horizontal water turbines by McAdam et al. [9]. The project consists of rapid prototyping modified blade designs for the water turbine and testing them in the water flume (Figure 13). Their desired range of water flow velocities varied from 0.2 ft/s – 2.0 ft/s. The water flume proved sufficient to meet the lower end of their test requirements. The students have successfully tested scale water turbines in the water flume and have collected sets of power generation measurements.
Student Learning Objectives and Assessment

The educational goal of the work presented in this paper was to demonstrate different means of reinforcing concepts in theoretical and experimental fluid mechanics. The particular objectives for students will vary based on whether they were a part of the fabrication of the water flume or if they are the end user. For students involved with the fabrication of the water turbine, this experience provides a broad exposure to the challenges of experimental fluid mechanics. By the completion of the project, the students will have:

1. Applied the fundamentals of fluid mechanics toward designing an experimental setup capable of modeling a flow for the purpose of meeting a design objective.
2. Integrated CFD modeling and experimental testing in the design process.
3. Learned the basic considerations for selection of a pump.
4. Became familiarized with working with piping, valves, and fittings as it relates to fluid mechanics experiments.
5. Received exposure to troubleshooting, diagnosing, and correcting problems that occur during the development of an experimental setup.
6. Demonstrated the ability to design and implement methods to assess the performance of an experimental setup.

The water flume presented was the work of a single undergraduate student, who is also the lead author on this paper. There was no formal written assessment of the student prior to the start of the project with regards to the objectives. However, it could be argued that the student has
demonstrated meeting all of the objectives based on the completion of water flume and this paper. Similarly, the expectation is that a student constructing their own water flume should meet the learning objectives as a requirement to successfully complete the project. Unfortunately, the accuracy of any conclusions, even with quantitative assessment data, would be challenging given that there is only a single data point.

The objectives for the students who use of the water flume would be different because they were not directly involved with the development. For students that use the water flume in an educational environment, their experience should have:

1. Reinforced dynamic similarity in fluid mechanics.
2. Reinforced the basic operating ideas behind external flow testing devices such as water flumes and wind tunnels.
3. Reinforced the understanding of external flows.
4. Introduced the methods involved with the construction and operation of fluid mechanics experiments.
5. Provided hand-on application of concepts from instrumentation for the measurement of relevant data.
6. Exposed students to the challenges of collecting electronic measurements from submerged components.

For the assessment of these objectives, data were collected from the students currently using the water flume for their senior capstone project. The group consists of 5 senior mechanical engineering undergraduates. Self-assessment surveys were given to the students asking if they agreed that their work with the water flume achieved the objectives above. A score of 5 means that the student strongly agreed that the objective was met while a score of 1 means that the student strongly disagreed that the objective was met. The results of the survey are shown in Table 3.

Based on the results, the students on average assessed that their work on the water flume met the learning objectives, although to varying degrees. They only somewhat agreed that their fluid mechanics knowledge was reinforced, with a consistent average rating of 3.8 on the first three objectives. However, they strongly agreed with the latter three objectives related to experimental fluid mechanics, with scores varying from 4.4-5.0. The students unanimously agreed that this experience was a direct application of their instrumentation knowledge in an experiment. This outcome was not unexpected since their project objectives are weighted toward experimental measurements. For their project, the students were not given any supplemental instruction in fluid mechanics nor asked to carry out specific assignments to reinforce concepts in fluid
mechanics. Overall, it is encouraging that the students did find their usage of the water flume as a learning experience in all aspects.

There are caveats with presented results. Self-assessment data can be affected greatly by student biases toward underrating or overrating their performance. This phenomenon has been well documented in education research [10,11]. In addition, the small sample size makes broad conclusions difficult to draw. These two concerns will be addressed going forward once the water flume is used in the Fluid/Thermal Laboratory course. The total course size numbers 40 students and their progress can be tracked from entry into course, through the use of the water flume, to the end of the course. Assessments can be made from their graded materials over the span of the course, in addition to self-assessment surveys.

Table 3. Results of the self-assessment survey taken by the senior capstone project group using the water flume. A score of 5 means strong agreement that the objective was met. A score of 1 means strong disagreement that the objective was met.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Average Score</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reinforced dynamic similarity in fluid mechanics.</td>
<td>3.8</td>
<td>1.1</td>
</tr>
<tr>
<td>2. Reinforced the basic operating ideas behind external flow testing devices such as water flumes and wind tunnels.</td>
<td>3.8</td>
<td>0.84</td>
</tr>
<tr>
<td>3. Reinforced the understanding of external flows.</td>
<td>3.8</td>
<td>0.45</td>
</tr>
<tr>
<td>4. Introduced the methods involved with the construction and operation of fluid mechanics experiments.</td>
<td>4.4</td>
<td>0.55</td>
</tr>
<tr>
<td>5. Provided hands-on application of concepts from instrumentation for the measurement of relevant data.</td>
<td>5.0</td>
<td>0.0</td>
</tr>
<tr>
<td>6. Exposed students to the challenges of collecting electronic measurements from submerged components.</td>
<td>4.8</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Conclusion

The overall goal of this project was to design and construct a water flume that allowed for the repeatable experimentation at low flow velocities. The majority of the design and construction process was completed by a single undergraduate. The exception to this was the fabrication of the testing tank and insert, where it is strongly recommended to work with a vendor that has experience in the field. The result was a water flume capable of low velocity flows of up to 0.6
The small footprint (7’ x 3.5’) and portable design objectives were met entirely. Although short of the 2.0 ft/s goal laid out in the initial objectives, the water flume is sufficient to replicate the lower end of river and ocean flows. The budgetary objective was partially met with a total cost of approximately $3500 for the version without the holding tank. To date, the water flume has been successfully used by team of students for their senior capstone project. Upon implementation of a new transparent test insert, a flow visualization setup can be introduced allowing the water flume to be used in future Fluid/Thermal Laboratory courses.

Future work on the project will focus on the instrumentation to make flow measurements in the test section. These instruments will be necessary to assess the quality of the flow profile in the test section. Those measurements are necessary to further refine the design and quantitatively characterize the quality of the flow. To address the short fall in the velocity performance for the same sized insert, the use of a larger pump is being explored. In addition, the implementation of a variable frequency drive is being explored for more precise control of the flow rate.

In terms of engineering education, the fabrication of the water flume was a positive educational experience for the student carrying out the project. The objectives derived were considered met but the single data point makes drawing general conclusions a challenge. The self-assessment of seniors using the water flume for their capstone project found that they strongly agreed that their experience with the water flume strengthened their experimental skill set. They did not feel as strongly about the reinforcement of theoretical fluid mechanics concepts. Again, the limited sample size presents a challenge in drawing broad conclusions. Going forward, better assessment data can be collected when the water flume is implemented into the senior Fluid/Thermal Laboratory class. The class offers a larger sample size and more points of assessment.

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References


