

The Design and Construction of an Open Channel Recirculating Water Tank
for the Study of Biological Hydrodynamics

by

Thomas V. Hennessey III

Submitted to the Department of Mechanical
Engineering in Partial
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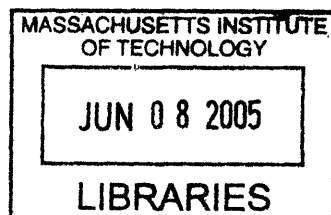
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ABSTRACT

This project chronicles the design and construction of a small scale recirculating water tank for the purpose of studying biological hydrodynamics. Currently available systems were analyzed and studied prior to developing a new, cost effective design that provides laminar flow through a two foot test section. Construction details provide the information for duplicating a low cost water tank for fluid flow and visualization.

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Table of Contents

1. Introduction	p. 4
2. Design and Construction	p. 6
2.1 <i>The Contraction Section</i>	p. 6
2.2 <i>The Test Section</i>	p. 8
2.3 <i>The Receiving Tank</i>	p. 10
2.4 <i>The Return and Supply Piping</i>	p. 12
2.5 <i>The Pump</i>	p. 12
2.6 <i>The Support Structure</i>	p. 13
2.7 <i>Total Cost</i>	p. 15
3. Tunnel Operation	p. 15
4. Future Improvements	p. 17

Chapter 1

Introduction

To study the biological hydrodynamics of fish, a recirculating water tank must be used to keep the subject in one position, while still allowing it to swim. The fish must exhibit normal swimming characteristics while staying in the same static location so instruments can record the important parameters of the water flowing past the subject. Potential instruments that may be incorporated into the tank include video recording, a dye-injection system to track fluid flows, as well particle image velocimetry (PIV) equipment.

Currently, several commercially available water tunnels provide the same basic function, as the goal of this thesis; namely, a reasonably sized test section with smooth, laminar flow throughout. The smallest system on the market provides for a test section which is approximately 6" x 6" x 18" with variable speed control of up to 1.5 m/s. These models are designed to minimize turbulence and variation in flow from the structural design of the pumping and return piping. Common to these models are flexible couplings meant to diminish the effect of outside vibration on the water flow. Other extra features include laser-leveled components which ensure the matings between pieces are flawlessly balanced and level.

While these characteristics ensure reliability and extreme accuracy, these added degrees of precision are overly sufficient for the level of study that will be conducted in this tank. The necessary features for the study of biological hydrodynamics most

importantly include, laminar flow through the test section, and a method to vary the speed of flow. The flow should be laminar within 2cm of the walls of the test section. The goal of this thesis is to provide these capabilities at a fraction of the price of current models.

By developing a new method for creating such water tunnels, these systems could be more easily incorporated into educational uses. This design might attract the interest of high schools or colleges, which are not interested in spending upwards of \$20,000 for a practical demonstration fluid tunnel.

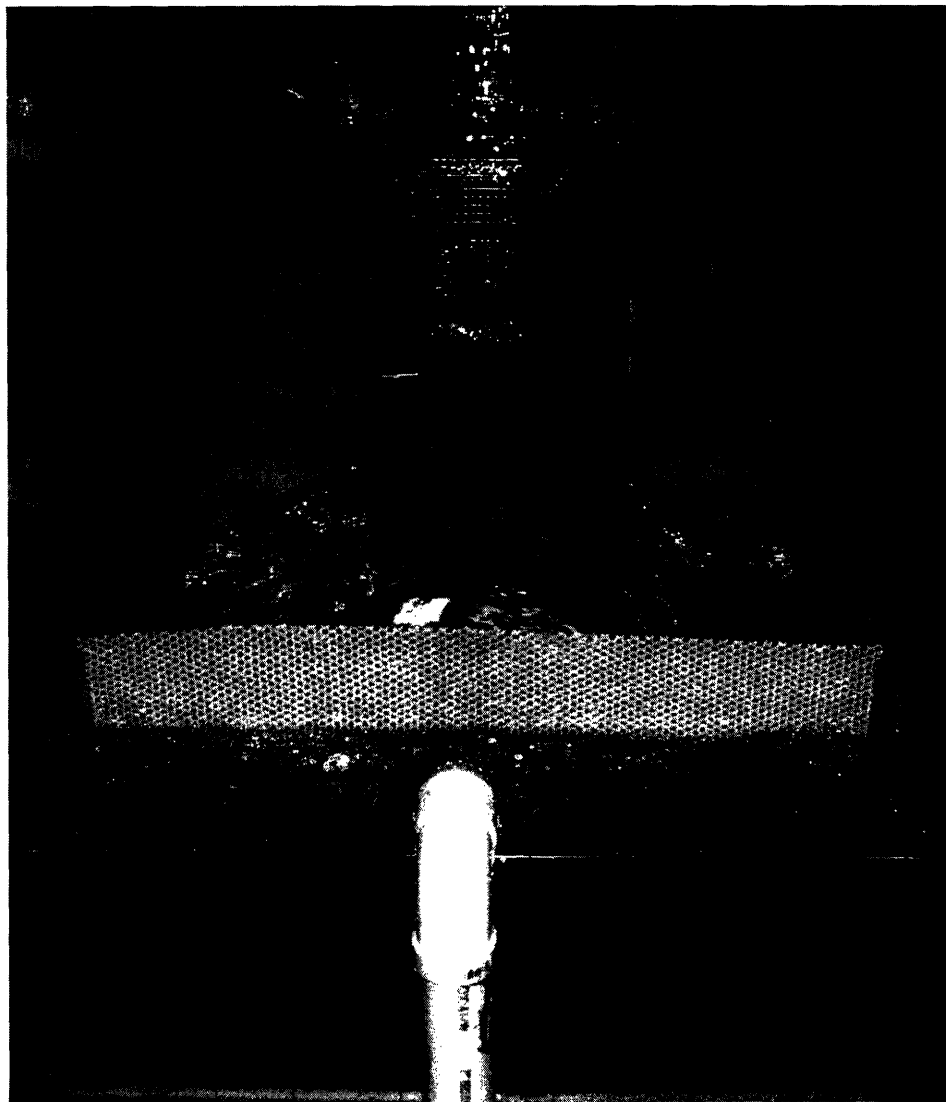


Figure 1: Recirculating water tank, view from upstream end.

Chapter 2

Design and Construction

The main purpose of this thesis was to design and construct a small recirculating water tunnel. The water tunnel has 6 main components:

- 1) The contraction section*
- 2) The test section*
- 3) The receiving tank*
- 4) The return and supply piping*
- 5) The pump*
- 6) The support structure*

By using readily available parts, and eliminating some of the precision that will not be needed for this application, the commercially available system can be simplified and modified. The design and construction of each part of the tunnel is discussed in the following sections.

2.1 The Contraction Section

This is the most elaborate and expensive piece of the water tunnel. To maintain laminar flow in the test section, the incoming water must be passed through straightening screens (8mm honeycomb polypropylene) in a wide section, where the flow is slow. There are two screens spaced 6 inches apart in the settling area of the tank before the contraction. The flow must then be reduced to pass through the test section which has an approximate surface area of 5 inches x 8 inches. The smallest ratio that will allow for the flow to remain laminar is 6:1, thus the beginning of the contraction section must be at least 240in².

The actual section was welded out of 1/16-inch stainless steel. The contraction was created by bending the ends of a stainless steel sheet at 10 inch radii (in reverse directions at each end) and then welding them to the base, 32 inches at one end, 6 inches at the other. The seams around the tank are sealed with silicone to protect the joints from rust.

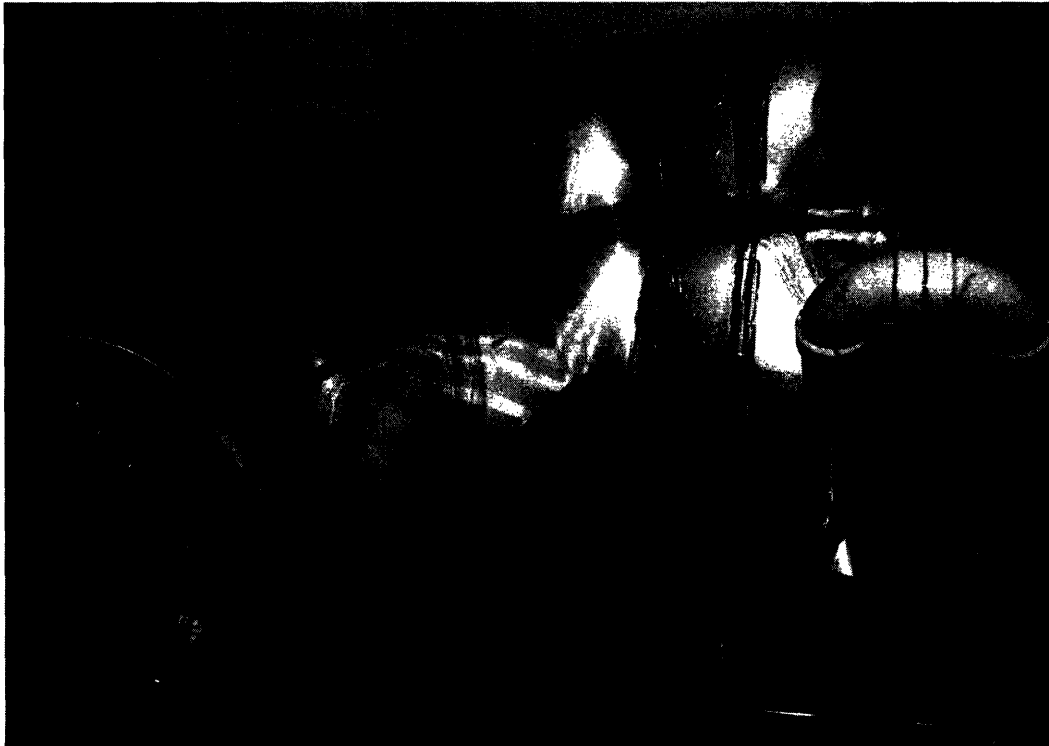


Figure 2: Contraction section, from above.

The end mating to the test section has a 2-inch flange around the bottom, and sides with 29 holes spaced evenly every 7/8-inch. A matching flange was made and joined to test section. It was then fastened to the contraction section with 1/4 inch stainless steel bolts and flange nuts. The gasket was constructed of 1/16 adhesive silicone sheets. Once the sections were mated, silicone aquarium sealant was applied to the inside joint to ensure a watertight seal, and to smooth the transition from the stainless steel to the

fiberglass. The welding was done by MIT's central machine shop for approximately eight hundred dollars.

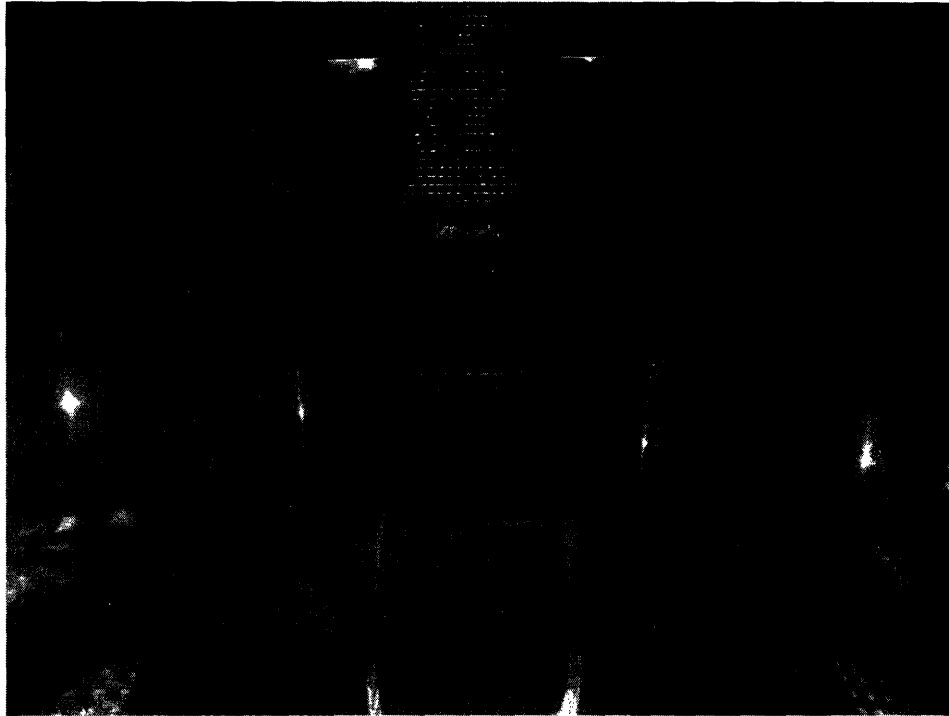


Figure 3: The contraction section, from inside.

2.2 The Test Section

The test section was formed from three pieces of 3/8 inch thick clear acrylic, fused together, leaving the top of the channel open. The stainless steel flange was fastened to the test section with a structural adhesive, methyl methacrylate, before being bolted to the contraction section.

The test section is nominally 24 inches long and the downstream end is fastened directly into the receiving tank. Due to the flanges and the fastening at the downstream end, the test section has a 21.5 inch visible length with a 5 inch width and 10 inch depth. A 2 inch addition to the height acts as splash guard.

Joining of the acrylic was done with dichloromethane applied with a syringe to the joints and surfaces being mated. Dichloromethane is a chemical welder that melts the two pieces of acrylic into a solid piece. The surfaces were lightly etched with 220 grit sandpaper to increase the surface area of the bonded surfaces. The pieces were then bolted into place with pipe clamps, with small bits of 24-gage wire slipped in between the joints. The dichloromethane was injected and drawn into the joints by capillary action. The wires were removed, and the clamps applied at full clamping force and allowed to sit for 48 hours. Silicone was not used in this section to maximize optical clarity from all angles.



Figure 4: The test section, side view.

The end of the test section protrudes $\frac{1}{2}$ inch into the receiving tank to allow for unrestricted flow through the test section. The two sections are mated with dichloromethane as well as sealed with silicone. As an additional measure to ensure watertight joints, a matching flange was secured and sealed with silicone around the mating. Including adhesives, this section cost about one hundred and seventy dollars,

with the bulk of the cost used for the stainless steel flanges and stainless steel fastening hardware.

2.3 The Receiving Tank

The receiving tank is constructed of 3/8-inch thick acrylic pieces welded chemically into a rectangular tank. A rectangular hole, sized to the test section end was cut in one side of the tank, allowing the test section to protrude 1/2 inch into the receiving tank. The tank is nominally 24 inches (length) by 18 inches (width) and by 15 inches (height). The bottom of the receiving tank has a 3 inch diameter hole centered 6 inches from the back of the tank. A hand-tightened compression bulkhead fitting joins the receiving tank to the drain system, 2 inch PVC piping.

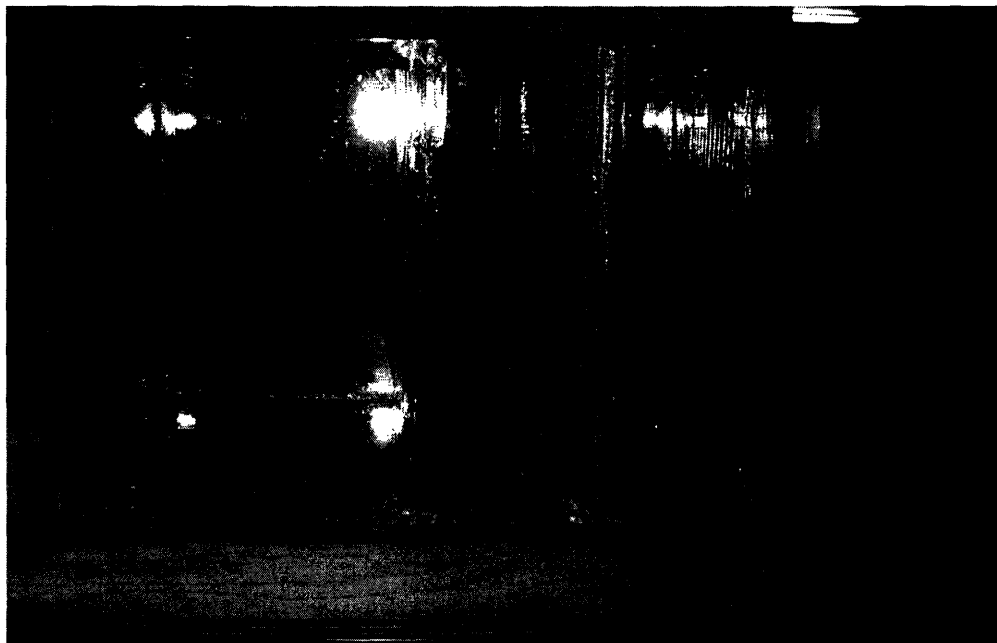


Figure 5: The receiving tank, side view.

A section of stainless steel mesh cloth serves as a filter between the transition from the test section to the receiving tank. Acrylic supports are fastened to the inside walls of the

receiving tank to guide and hold the mesh cloth in place. The mesh is composed of squares (.423 inches a side). Similar to the test section, all joints were welded together through the capillary action of dichloromethane. For extra security, these seams were covered with silicone after the plastic welder had dried. Testing revealed that a slightly larger receiving tank would function better in this system. The current tank allows for some slight back flow from the exiting water of the test section after the flow hits the far wall in the receiving tank. To solve this, two sets of frames were installed in this section of the tank, designed to hold rectangular sheets of the 8mm honeycomb polypropylene. Either one or two sheets of honeycomb can be installed, depending on the needs of the user. These screens have successfully damped out the return of water to the test section. The approximate cost of this section is also one hundred and seventy dollars.



Figure 6: The receiving tank, end view.

2.4 The Return and Supply Piping

The return and supply piping is fashioned out of 2 inch PVC piping. Just before the piping enters the pump, the water passes through its lowest point of the system. Here there is a drainage valve which will allow purging of the system. The system of tanks is slightly elevated, approximately $\frac{1}{4}$ inch height differential from the highest point, the contraction section, to the lowest point, the receiving tank. This ensures easy draining of the system.

After passing through the pump, there is a ball valve which controls the speed of flow through the system. A variable speed AC controller is also wired to the pump to allow for fine tuning of the speed. A “U”- shaped set of discharge pipes returns the water to the contraction section without compromising the stainless steel tank running alongside the tank and then discharging from the top. The piping and valves cost approximately thirty dollars.

2.5 The Pump

The pump is a $\frac{3}{4}$ horsepower aquarium pump, capable of producing flow through the system of up to 1 m/s. The pump is a centrifugal pump which should minimize turbulent flow. To vary the flow speed, several ideas were investigated including varying the incoming voltage with a rheostat or SRC controller. Currently, the variable speed AC controller is used in conjunction with a ball valve. Other possibilities for regulation included a gate valve or a butterfly valve. Due to cost and performance standards, the ball valve was chosen.

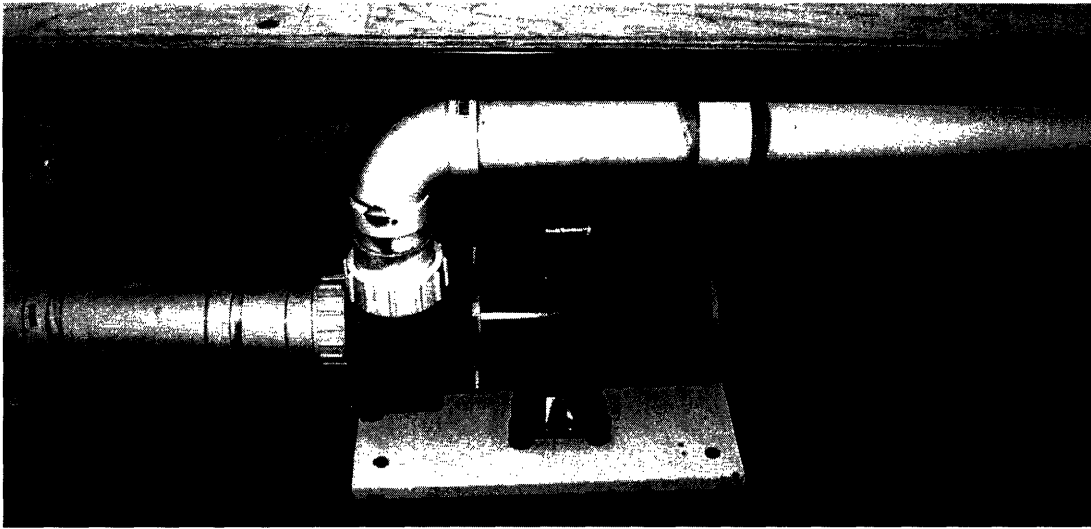


Figure 7: The pump, side view, mounted on tunnel frame.

This pump was selected because of its availability; it was an extra from an old experiment. A comparable pump would cost about three hundred dollars, but depending on speed requirements, a smaller, less expensive pump could be used.

2.6 Support Structure

The support structure for the system is mainly composed of 1-⁵/₈ inch by 1-⁵/₈ inch galvanized steel pre-slotted sections with channels running down the length of the opposite side. This type of construction ensures maximum flexibility for future modifications. The structure is easily assembled, yet rigid and strong. It is 30 inches wide by 88 inches long.

The top of the structure is covered with ¹/₄ inch plywood serving as a tabletop to support the various tanks. Two rectangular holes are cut through the wood, one 14 inches by 28 inches to allow for complete visibility of the test section, and another smaller hole for the bulkhead fitting/drain from the receiving tank.

To elevate the entire contraction section 2 inch ribs were used. By raising the contraction section, the test section is elevated as well, providing better visibility and access. Additionally, the receiving tank then has a 1- $\frac{3}{4}$ inch deeper bottom than the test section. By keeping these mated sections at different depths, back flow into the test section should be minimized.

The pump is mounted onto a riding carriage on a set of rails beneath the tanks on vibration isolating supports. Also on the carriage is a surge protector that functions as a power supply switch for the system. There is additional room both on the carriage and behind the receiving tank to mount additional equipment. For cleaning, draining, or modifications, the ports to the pump can be disconnected from the pump, and the entire carriage slid out of the way. All components for the support structure cost one hundred and twenty dollars.

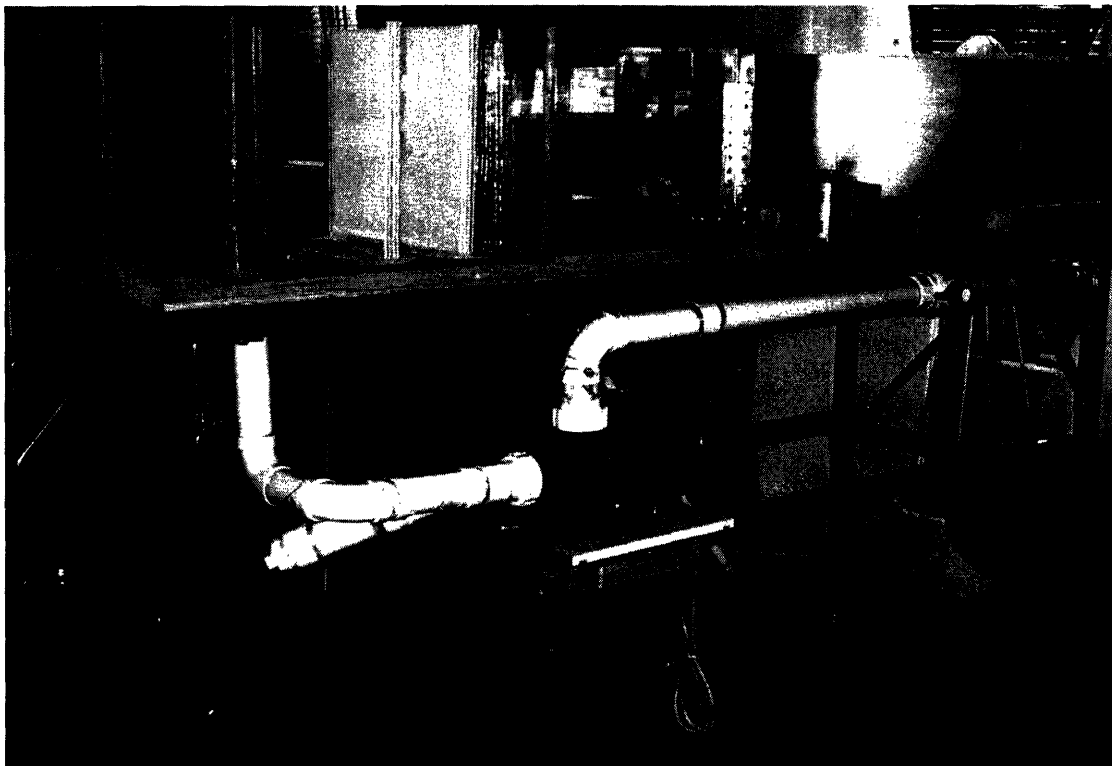


Figure 8: Support structure and return piping.

2.7 Total Cost

The total cost of construction is given below. The cost of each section noted above is as follows:

Contraction section	: \$800
Test section	: \$170
Receiving tank	: \$170
Piping	: \$30
Pump	: \$300
Support structure	: \$120
Total Cost:	\$1590

Chapter 3

Tunnel Operation

The maximum depth of water that should be used in the system is 10 inches. The flanges are supported and fastened up to this height. An additional 2 inch height could potentially be used; giving a maximum depth of 12 inches, but these 2 inches are not supported by the flange and only sealed with silicone. Its primary function is as a splash guard, however, 11 inches of water have been in the tank without compromising the watertight integrity of the system.

Ideally, speed control can be adjusted precisely using the combination of physical restriction (the ball valve) and variation of the pump's speed (AC controller). To drain the system which contains roughly seventy-five gallons of water, the one inch drain plug can be removed with a wrench. Due to the gravitational potential energy of the water, it is

recommended that as much water as possible be drained via a bilge pump directly from the system before opening the plug.



Figure 9: Above: Water tank filled to typical operating depth. Below: Tank operational, note the single flow straightener.

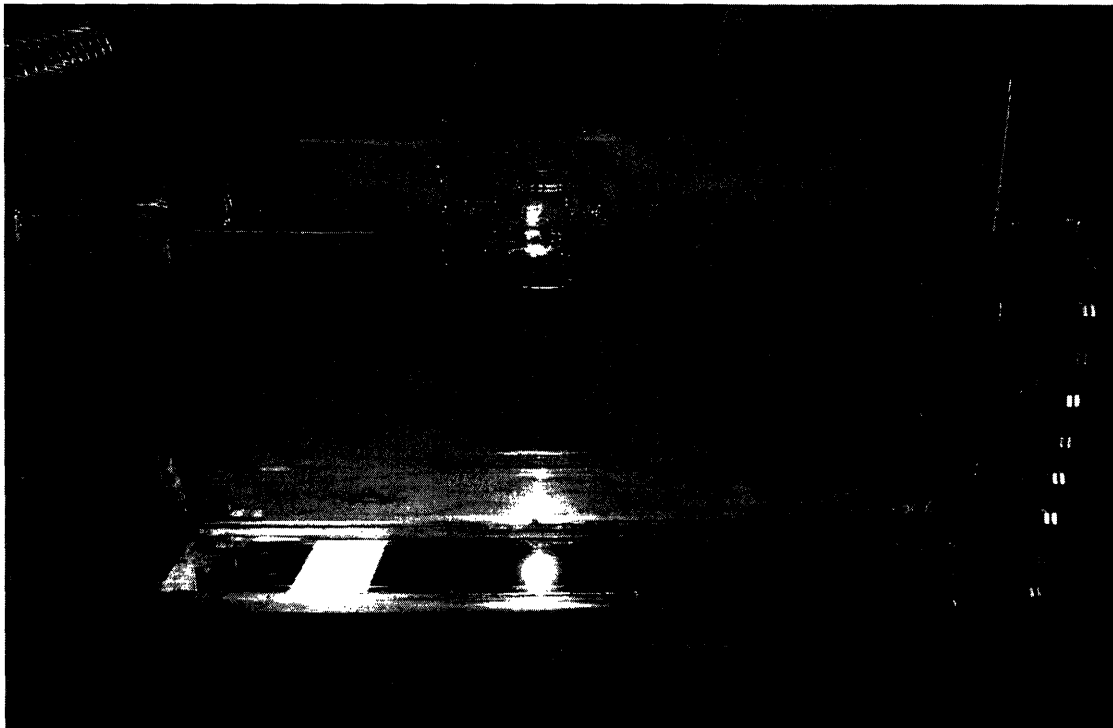


Figure 10: Flow through test section.

Chapter 4

Future Improvements

The most significant improvement to the system would be the addition of a more robust electronic voltage controller for the pump. The current controller does not have the smoothest interaction with the pump. The pump appears to have a minimum voltage required for operation, however, on the current AC controller the threshold voltage is almost at the extreme range of the dial, thus not allowing for significant voltage regulation.

Additionally, the honeycomb screens that serve as flow straighteners, in the contraction section, and flow dampeners, in the receiving tank, could be more rigid. The current honeycomb is a composite of individual straw-like channels glued together every

8mm. The honeycomb would be more rigid and effective if it was set in a frame with supports across its face.



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