Design and Development of Low-speed Water Tunnel

Mujahid Saeed[1], Emad Uddin[2], Aamir Mubashar[3]
[1,2,3] Computational Mechanics Group, School of Mechanical and Manufacturing Engineering (SMME),
National University of Sciences and Technology (NUST),
Islamabad, Pakistan.

Salim Uddin Zahir[4]
[4]CESAT
Islamabad, Pakistan
Ali Abbas Zaidi[5]
EME, NUST

***Abstract*— The water tunnel is an essential exploratory office utilized for examining the hydrodynamic behavior of submerged bodies in the flow of water. Its use in checking the behavior over various structures and analyzing the boundary layer process (i.e. separation of flow, shedding of vortex etc.) makes it more useful over other counterpart facilities. The principle of operation of the water tunnel resembles the wind tunnel but in the wind tunnel, air is used as working fluid instead of water. Water tunnel has higher capacity for pumping of flow than wind tunnel. In water tunnel, visualization of flow is easier than wind tunnel due to higher viscosity of water and various kinds of techniques for visualization can be used. This paper discusses the design, fabrication, and analysis of low-speed water tunnel that was assembled as a part of this research. The water tunnel has dimensions of WHL 2x1.5x8 meters with a capacity of 2000 gallons and weight 500 kg without water. Material used for the tunnel is aluminum with a thickness of 3mm, which has suitable strength against hydrostatic forces. Aluminum is corrosion resistant in case of water. Various parts, their uses, and different changes that require to be made during their design are discussed. The test section dimensions were taken as WHL: 0.4 x 0.5 x 2 m with the flow velocity range of 0-0.5 m/sec. Contraction ratio of 5 is used and L/D ratio is taken as 1.16 for the contraction chamber. The pump used for water circulation is centrifugal type with specifications of 10 hp and 1100 GPM. The purpose of the water tunnel is to obtain uniform and steady speed of flow in the test section. This tunnel is well suited for Particle Image Velocimetry (PIV). The water tunnel developed will be utilized to conduct the low Reynolds number experimentation for different objects. The water tunnel can also be utilized for the purpose of education such as fluid mechanics lab activity to learn about different topics taught in the class.**

Keywords—hydrodynamic; fluid; submerged; tunnel; steady; centrifugal

I. Introduction

A water tunnel is a setup which is to study the hydrodynamic nature of the bodies submerged in water. It is similar in working to wind tunnel but differentiate due to fluid working inside. But another helpful application of water tunnel is flow visualization of submerged bodies. It is also good for the calculations of PIV because it is simple and well suited to use in water instead of any other fluid. For the flow with low Reynolds number, oil will be good as a working fluid instead of water. It will provide the benefit of speedy flow for a lower Reynolds number due to enhanced kinematic viscosity.

Water tunnels stand in the class of experimental aerodynamics. It is suitable for students to use it in laboratories for experiments. Test bodies and models used in water tunnel can be manufactured faster and at very low cost than that of wind tunnels.

Visualization of flow over various test bodies plays a vital role in examining nature of flow over a test body for aero dynamic and hydrodynamic. Simple explanation is available in case of water tunnel and wind tunnel. Wind tunnel is appropriate for the flow visualization of high speed but proper technology is required for visualization of flow e.g. high speed camera. Every now and then it is impossible to perfectly view flow over test body at very low speed [1]. In this case, water tunnel is the best option.

Because of the low velocities of the micro aerial vehicles, water tunnel is very beneficial to analyze their nature. Fluid flow over test body may be quite simple; additionally very little energy, price and technology may be required to visualize it. Water tunnel is a good option for the analysis of different submerged bodies [2].

Therefore, the present facility of water tunnel is planned to concentrate upon the flow visualization over different test models. It also helps to make the impressions of Vortex Induced Vibrations (VIV) visible upon immersed bodies. It is very helpful for future research work and other educational purposes. This tunnel is well suited for PIV. It is also suitable for low Reynolds number experimentation. It helps in performing experiments in uniform and steady conditions. The word steady indicates no change at a point w.r.t time while the word uniform indicates no change w.r.t position over a particularized area [3]. It identifies the capacity of water tunnel to determine functional complications of fluid mechanics.

II. Literature Review

In the ancient days, flow visualization has been executed by water tunnels thoroughly utilizing graduated systems, for example, aircrafts. Water tunnels have more advantages over wind tunnels in these fields because greater density and smaller mass diffusivity of water as compared to air and the main thing utilized in wind tunnel i.e. free stream velocities are usually more than those utilized in water tunnels. Researcher can gain an awareness of fluid dynamics of stream because the usage of water tunnel to visualize the flow provides a vision into complicated attitude of flow across the testing body.

Kalyankar et al. planned and manufactured water tunnel having test section with magnitude of 100x150x700 mm. This system was able to produce a stream velocity in the middle of 0mm/sec and 210mm/sec. Another application was to carry out flow visualization by utilizing method of external dye inoculation. Other manufacturers were Kirloskar Brothers Limited who manufactured pump that propagated water throughout the whole system having flow rate of 19.08 m^3/hr and highest-pressure head of 26m. They also planned other proper methods for dye inoculation. CFD analysis was performed to check the stream in the system. This system was therefore enhanced to undergo laminar flow across the whole water tunnel. The required velocity was attained as 8m/sec for distinct group of input specifications[4].

Basak and Mitra planned different parts of an open type blower tunnel with no outlet diffuser. They have prepared aerodynamic open jet wind tunnel design operated by a propeller of centrifugal type attached to settling container by a diffuser with expanded angle. The elect or the designs of screens, test section, contraction chamber, diffuser and propeller are narrated. The tunnel working strongly depends upon these parameters. The design principles and advices are properly established upon information grouped from workable design of blower tunnel. It is greatly profitable and sensitive to anticipate planned boundaries based upon the information from existent tunnels popular to operate adequately[6].

Table 1 contains a list of some of the most popular water tunnels in the world. This list is not that much vast but is a good illustration of the largest facilities presently available. The following list is arranged in random manner.

TABLE I. LIST OF EXISTING WATER TUNNELS

Water Tunnel	Possession	Test Section WxHxL (mxmxm)	Maximum Speed (m/sec)	Literature Reference
Large Cavitation Channel (LCC)	U.S. Naval Surface Warfare Center – Carderock (USA)	3.05x3.05x13	18	[7][8]
Flow Noise Simulator (FNS)	Naval Systems Research Center (Japan)	2x2x10	15	[9]
Grand Tunnel Hydrodynamique	Bassin d'Essais des Carènes (France)	1.1x1.1x6	20	[10]
St. Anthony Falls High Speed Water Tunnel	Univ. of Minnesota (USA)	0.19x0.19x1.3	20	[11]
Ceccio 9-inch Water Tunnel	Univ. of Michigan (USA)	0.21x0.21x1.1	18	[12]
ARL 6-inch Water Tunnel	Applied Research Lab at Penn State (USA)	0.15x 0.64 (round)	24	[13]
High-Speed Cavitation Tunnel (HiCaT)	Univ. of New Hampshire (USA)	0.15x0.15x 0.91	> 13	[14]

III. WATER TUNNEL DESIGN

This section focuses on the design of low speed water tunnel that may be utilized to study the flow visualization over different submerged bodies and for other research work and educational purposes. Fig. 1 shows the CAD model of water tunnel which is designed using Pro E software. The designs of preceding study were modified to get the present design [15][16]. The whole water tunnel is made of aluminum sheets with the thickness of 3mm. Aluminum resists water corrosion in a better way. This water tunnel is designed to perform low Reynolds no. experimentation.

Water is sucked from the suction provided at the Outlet Plenum aft the water tunnel. The pump suction was found to be more effective since it increases the water inlet to the motor and equal distribution of flow aft the water tunnel, hence the level of turbulence was reduce to the greater level. Water is then discharged through a single outlet in the inlet container of the water tunnel to reduce discharge velocity and turbulence. Water is re-circulated between the inlet and outlet continuously in close circuit.

The flow discharge and velocity of water in the test section is controlled by voltage regulator hence allows us to carry out test at various velocities ranging from 0 cm/sec to 5 cm/sec in the test section. By controlling the voltage to the motor, RPM of the motor is controlled, resulting into the control of water discharge through outlet and velocity.

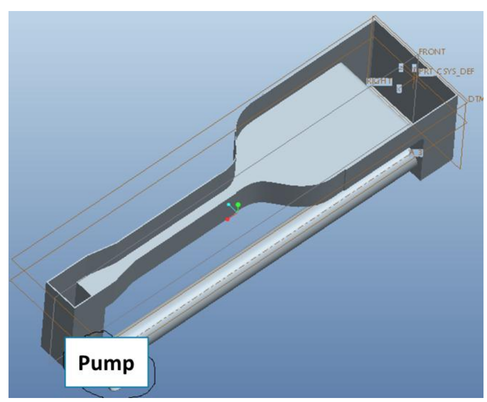

Fig. 1. CAD Model of Water Tunnel

A. *Test Section*

Test section is a major part of water tunnel. Test section is a part where important tests on various models are carried out and flow can be seen over a model. Following parameters were considered while designing the test section: test section length, velocity in test section and strength. As in this case volume of water is very large, that is why test section was made up of 10mm thick Acrylic glass (Fig. 2).

Fig. 2. Test Section

In order to get laminar boundary layer, the cross section was 0.4 x 0.5 meters and length was taken as 2 meters. The Acrylic glass is a very strong and rigid material with a transparency same as that of normal glass. Acrylic glass transmits more light than normal glass. The value of thermal conductivity is much higher than the glass. It is easy to clean in order to remove dirt. Acrylic glass has higher impact strength than normal ordinary glass. It sustains high pressure load. The main advantage of this is that it does not break easily on normal load impact. Its sides are screwed to the sides of the model. The base plate of acrylic was screwed to frame made of aluminum welded with the base of the model. The small gap between them is filled with Synthetic Resin (SR) to prevent leakage of water from the joints. Measuring scale is also attached to the test section to measure the level of water in it.

B. *Inlet Plenum*

Inlet plenum acts as a reservoir tank. It is the largest portion of water tunnel. Main function of the inlet plenum is to store the sufficient amount of water. When water pumps out from inlet through pipe then it is collected in inlet plenum. Because the area of inlet plenum increases drastically, the velocity of flow reduces which is higher than the diversion section[4][17].

In this case (Fig. 2), inlet plenum consists of two sections:

- First one is inlet tank which acts as a huge reservoir. Baffle plates are fixed in the tank to avoid deformation due to hydrostatic force. An aluminum plate of 6 mm thickness with holes of 16 mm dia. was fixed in it to reduce turbulence. It decreases turbulence intensity and enhances the uniformity of the flow[18].
- Second one is settling chamber which reduces flow velocity and turbulence intensity by providing space for water molecules. This chamber is rectangular in shape. Dimensions of settling chamber are LxWxH= 1500x1850x500 mm.

To provide sufficient amount of discharge of water to converging section we have retained some parameters such as:

- Width of the settling chamber must be same as that of width of converging section
- Length of the settling chamber must be 2 times of the inlet dimensions of test section, but we have preferred more than this to occupy more amount of water.

Fig. 3. Inlet Tank

C. *Honey Comb*

The purpose of honeycomb is to convert the turbulence flow to laminar flow and reduce the transverse component of velocity fluctuation. It is necessary to obtain the laminar flow while analyzing the models. The need for free stream turbulence level in water tunnel has increased over the last few years. Honeycomb must be placed before converging section to obtain the laminar flow in the test section[14][19].

In this case, honeycomb structure is made up of waterproof aluminum so that it does not lose its effectiveness. A frame of aluminum supports the honeycomb structure at its desired position and maintains its shape. Wire mesh of very fine grid strains any kind of impurities, which could damage the test model and flow over its surface. Its dimensions are 1850 x 152.4 x 500 mm (L x W x H).

Fig. 4. Honey Comb

D. *Contraction Chamber Design*

A source is required to achieve increased velocity in the test section. Therefore, after honeycomb section, there is a convergent section, which is helpful in decreasing turbulence intensity and increasing velocity. It is simple to construct with low chances of errors. The uniformity of flow at the outlet of contraction is improved with increment in length. The contraction ratio should be taken between 5 and 10.

Conceiving the interest of getting high velocity uniformity with low turbulence and manufacturing cost, contraction ratio of 5 was preferred[5]. With the test section of 0.4m width, the inlet width of the contraction chamber is to be taken as 2 m=5x0.4 m. The contraction chamber has uniform height of 0.5 m throughout the length with rectangular cross-section.

As width of inlet and outlet are fixed, the contour that joins these has to be determined. This profile is defined best by the 5th degree polynomial curve as:

$$Y = Wi - (Wi - We) \times [6(\frac{x}{L})^5 - 15(\frac{x}{L})^4 + 10(\frac{x}{L})^3] \qquad (1)$$

Where Wi shows the width of inlet, We is the width of exit while L is the length of contraction chamber. x is coordinate evaluated from the inlet of the test section to the inlet of the contraction chamber. The study shows that W/L ratio should be taken between 0.667 and 1.79, small value of L will cause decrement in turbulence dampening and boundary layer separation near inlet while large value of L will cause separation in boundary layer. This separation is caused by the region of adverse pressure gradient near the exit of contraction. So, L/W ratio of 1.16 was selected (L = 1.54 m).

E. Side Walls

Due to the curvature of the wall it was difficult to shape the aluminum sheet properly according to proper dimension. Even then this task was done with very hard work but took a lot of time to get it into proper shape.

Fig. 5. Contraction Chamber and Setting Chamber

F. Diffuser

Diffusers are mainly used to increase the pressure in a ductwork or pipe work system containing air or water. Flow uniformity and steadiness at the exit of diffuser are of greatest significance since this influences the execution of main component downstream[6]. Fig. 5 indicates the two different areas, the entry and exit. The length of the diverging section is the distance between the parallel section 1 and 2. Diffusers may be rectangular in cross-section, square or circular. They may have a straight diverging section or this may be bell shaped in order to guide the flow by making it more streamlined. The divergent section is downstream of the test section in the experimental setup. It is the region of increasing area and decreasing velocity. The present water tunnel facility has rectangular diffuser. As water does not expand like gases do, diverging angle must be low thus increasing the length according to the previous studies. In this case, divergence ratio is taken as 0.67 and semi-vertex angle as 11°. The length of diffuser is 500mm. The inlet cross section area of diffuser will be same as the cross-sectional area of test section.

Fig. 6. Diffuser

G. Outlet Plenum

The purpose of the Outlet Plenum is to connect the wide angle diffuser with the piping system to drain out the flow. The geometry of the Outlet Plenum is designed properly to avoid any type of irregularities occurred in the model which leads to the reverse flow or back pressure in the system which will disturb the results in the test section. Outlets with two openings are designed so that the water flow is distributed equally towards the holes thus making a smooth exit of the flow and prevents any back pressure in the system. A strainer is fixed between diffuser and Outlet Plenum to avoid any type of impurities to enter into pump. The dimensions of this section are taken as 790x790 mm with height of 1.5 meters.

Fig. 7. Outlet Plenum

H. Supporting Table

As the part of model present between inlet and outlet container was suspended in the air, it was difficult to bear the load of water. It was necessary to fabricate such a supporting structure, which could support the whole water tunnel. Therefore, a proper supporting table was designed and fabricated from 2 inch squared MS pipes. It is designed such that it distributes the load of water and supports the tunnel in a proper way.

Fig. 8. Supporting Structure

I. Plumbing System

Motor is connected to inlet and outlet by means of the flexible green pipes. Flexible pipes are used to avoid vibrations. One pipe with a dia. of 6 inch is connected to the inlet section of water pump for the suction whereas one delivery pipe with a dia. of 5 inch is connected to the motor. Delivery pipe delivers water to the inlet container to make it able for recirculating the water connected at the water outlet i.e. before the converging section. M-seal is used to prevent leakages from the pipe.

MS metal bends are used at the corners and mild steel metal connectors are used to attach the pipes to the water tunnel. Flexible green agricultural pipes are used for the connections because of their durability and semi-rigid nature. Flexibility of the pipe was found to be very effective in reducing the effects of vibration of the motor in test section and in whole apparatus. Water pump is mounted on separate stand with rigid base to avoid any interference of vibration with the test apparatus.

J. The Pump

The pump used is of centrifugal type with the power of 10hp, capable of producing flow through the system of up to 0.5 m/s. For this low speed water tunnel, the pump can achieve the maximum water velocity of 0.5 m/sec in the test-section where as the minimum water velocity was found to be 0.2 m/sec by means of voltage regulator. It minimizes turbulent flow. To vary the flow speed, various concepts were examined involving changing the entering voltage with a VFD controller. Currently, a variable speed AC-controller is used in conjunction with a ball valve. Other possibilities for regulation included a gate valve or a butterfly valve.

Fig. 9. Pump

The specifications of the pump are given in Table II.

TABLE II. PUMP SPECIFICATIONS

OPERATING CONDITIONS

Medium	Clear water free from sand and silt.		
Technical Data		Pump Dimensions	
Capacity	3 Cusec	Pump Model	125 FCM-202
Total Pump Head (H)	15 Ft.	Suction Flange I.D	6"
Speed	1450 RPM	Discharge Flange I.D	5"
Specific Gravity	1	Coupling Type	Flexible
Pump Input	7.29 HP	Sealing Method	Gland Packing
Pump Horse Power	10 HP		
Material Specification		**Motor Specification**	
Pump Casing	Cast Iron	Make / Type	Siemens / Horizontal
Impellers	Cast Iron	Motor Rating / Pole	10 HP / 4 Pole
Discharge Cover	Cast Iron	Voltage	380 ± 5%
Pump Shaft	Carbon Steel	Phase	3
Bearing Pedestal	Cast Iron	Frequency	50
Suction cover	Cast Iron	Protection / Insulation Class	IP 55 / F
		Ambient Temperature	40°
		Enclosure	TEFC

IV. PROBLEMS FACED DURING THE FABRICATION OF WATER TUNNEL

After the completion of fabrication process, some problems were faced which were very difficult to tackle.

1. First was an uncontrollable leakage in the test section due to gaps between acrylic sheets and between aluminum sheet and acrylic sheets. Then there was also leakage in the elbows used to connect pipes with pump suction and delivery. This problem was first tackled by silicone gel but in vain. The epoxy resin was used which helped us completely to reduce the leakage.

2. Second was the extreme deformation in the inlet and outlet tanks due to the hydrostatic force of water on the walls. This problem was removed by using metal MS angles of about 3 inches on the two opposite sides of the tanks connected by studs having diameter of about ¾ inches, which restricted the walls to its original position.

V. WATER STORAGE SYSTEM

To avoid the water from wasting and for easy maintenance of water tunnel, this facility has been connected with the 4 high quality fiberglass water storage tanks having capacity of 500 gallon each. These tanks are combined water tunnel through 1 hp centrifugal pump which enables the water to remove from water tunnel to the fiberglass tanks and then gets back the same water to water tunnel when needed.

VI. DYE INJECTION SYSTEM AND STAND

For the purpose of dye injection, 3 syringe needles are used with their tips fin finely grinded to make a perfect circular section. Needles are connected to the bottles with intravenous kit. Stand for mounting needled is made up of iron strip. Needles are placed at a mid-section of test-section.

Fig. 10. A Complete View of the System

VII. CAMERA STAND

For the purpose of mounting camera to shoot the flow visualization while performing the practical flow analysis, cyber shot is positioned to provide the top view of test model. Camera stand is made up of aluminum with camera mount.

VIII. TEST MODEL MOUNT

Models in the test section are mounted on a stand made up of metal MS. It allows test model to set at various angle of attack and rotate at an angle of 180^o. Stand also facilitates model to position at any desired position or length along test section (up and down and to and fro).

CONCLUSION

This work enabled us to use this tunnel for load cell calculation. This facility is well suited with PIV. It can be used for low Reynolds no. experimentation. It produces uniform and steady flow, which is well suited for research work and educational purposes to perform experiments. This tunnel is free of every type of leakage. This facility is the best suited for research in the area of Fluid Structure Interaction (FSI). This tunnel has also capability to study different properties of flow visualization.

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