Low-Velocity Water Tunnel for Biological Research

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Abstract

A NEW type of water tunnel has been developed for research in the hydrodynamics of marine botany and other areas having related phenomena. The design criteria were: 1) low cost (a $10,000 limit on the cost of tunnel and instrumentation) and 2) smooth, uniform flow at velocities from 3 to 30 cm/s, representative of oceanic conditions, and with a working section size of 10 cm diam and 100 cm length, suitable for test of macroalgae. This paper presents the water tunnel's design, its operating characteristics, and an example of its use.

Contents

A water tunnel has been developed at the University of California at Santa Barbara for studies of the effects of water motion on the life processes of marine plants and other low-velocity hydrodynamic phenomena. The design criteria were: 1) the cost of the tunnel cannot exceed $10,000 including tunnel structure, pumps, flow control devices, and instrumentation, 2) flow must be smooth (very low turbulence) and uniform from 3 to 30 cm/s in a working section 10 cm in diameter × 100 cm in length, and 3) the tunnel must run continuously at a constant velocity for an indefinite period of time. The $10,000 construction limit eliminates the use of an axial flow pump, a type almost universally used in other water tunnels. Centrifugal pumps with the flow capacity desired are available and relatively inexpensive. Unfortunately, the flow from a centrifugal pump is surgy and turbulent and not at all suitable as a test medium for the water tunnel. The basic problem is to design a low-velocity, low-turbulence water tunnel driven by a centrifugal pump.

The solution is found in the relatively low velocities required. The maximum velocity, 30 cm/s, can be generated by an hydraulic head of only 0.5 cm, a small height compared to the dimensions of the working section. This modest hydraulic head suggests a gravity system operating at a constant head many times greater than the minimum required head of 0.5 cm. In a constant head system, the velocity at the outflow downstream of the working section is constant. The velocity in the working section depends on the flow rate which is controlled by an orifice placed in the outflow. A special valve enables the orifice to be changed easily and rapidly.

The flow to the reservoir returns to the sump partly through the working section and partly through an overflow return line. Thus the tunnel runs at constant hydraulic head regardless of surging in the pump pressure or changes in the velocity in the working section. Turbulence in the pump flow is eliminated by diffusors and baffles in the reservoir and a honeycomb and screens in the flow control section ahead of the working section. Difficulties with trapped air and bubbles were solved by orienting the tunnel's axis vertically and by building the section containing the honeycomb and screens as a separate unit which could be assembled underwater and inserted in the top of the tunnel without exposure to the air.

Figure 1 is a scaled sketch of the vertical water tunnel. The distance from the floor to the top of the reservoir is 3 m. The total volume of water in the tunnel during a run is approximately 200 liters. The water flows from the reservoir into the 20-cm-diam flow control section, through a contoured fairing into the 10-cm-diam working section, through a second contoured fairing into a short 5-cm-diam pipe, and out through the orifice in the orifice plate of the slide valve. The jet from the orifice plate traverses a short path of open air (at ambient pressure) before entering the sump, thus establishing the hydraulic head. In addition, a chiller unit circulates the water in the sump through a heat exchanger and maintains the water at a controlled temperature.

The tunnel is instrumented for flow visualization by dye injection and for the measurement of velocity and turbulence by a hot-film anemometer. The dye, a 0.5% solution of methyl blue, is injected through a hypodermic tube in the 20-cm section. Velocity and turbulence are measured by a hot-film anemometer operated in the constant temperature mode. The water in the tunnel is filtered to a mean particle size of 2 microns to insure reliable operation of the hot-film sensor. With filtered water, the hot-film anemometer provided accurate, repeatable measurements of both the average and fluctuating components of velocity.

The flow is smooth and uniform. Figure 2 compares the flow with and without the flow control section. With the flow control section, the dye streamer traverses the length of the tunnel without wavering and without any noticeable increase in diameter. The anemometer record indicates that the turbulence is less than 1%.

The constancy and uniformity of the flow combined with the dye marker and hot-film anemometer techniques enable the experimenter to record the dynamics of the flow in detail and with precision. Figure 3 shows the flow around a flat plate with a sharp leading edge and a blunt trailing edge. The

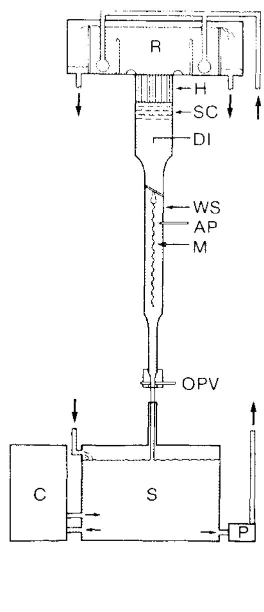

Fig. 1 Sketch of vertical water tunnel (axial section). Dimensions are scaled, direction of water flow is indicated by arrows. AP = anemometer probe, C = chiller, DI = dye injector, H = honeycomb, M = model, OPV = orifice plate valve, P = pump, R = reservoir, S = sump, SC = screens, WS = working section.

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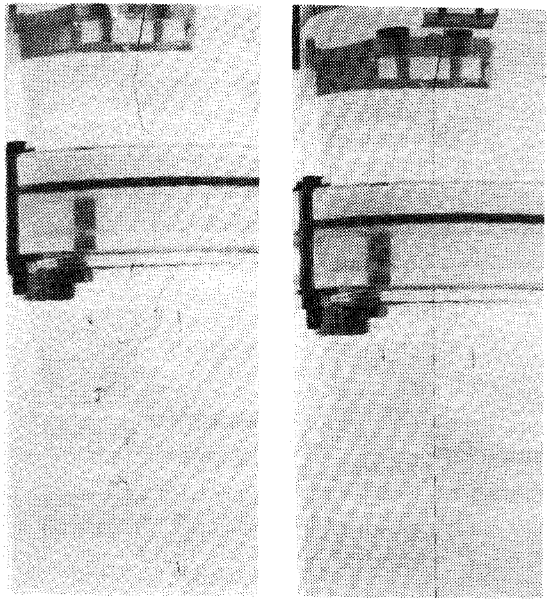

Fig. 2 Comparison of flow in working section with and without flow-control section in tunnel circuit: left-hand photo shows dye streamer with flow control section removed; right-hand photo shows flow dye streamer with flow control section in place; velocity = 5.5 cm/s; length of dye stream seen in right-hand photo = 17 cm.

dye stream is centered on the leading edge where it splits into two dye streams passing along the top and bottom of the plate. This dye stream configuration is very steady and does not change over long periods of tunnel operation. The flow in the boundary layer of the plate is laminar, in accord with previous experiments, since the Reynolds number based on plate length is 16,200, far less than the usual transition value. The flow in the wake is a well-defined Karman vortex street. The anemometer record gives a similar result for the wake flow since it shows a periodic, almost sinusoidal fluctuation in the velocity, corresponding to the vortex street flowing past

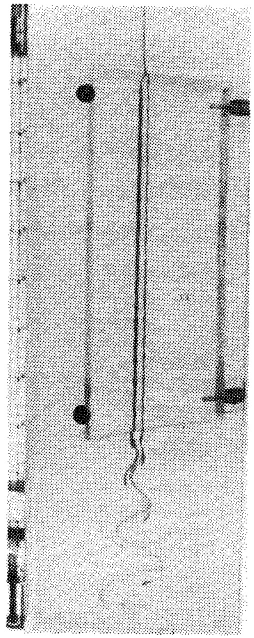

Fig. 3 Flow over flat plate with sharp leading edge and blunt trailing edge; velocity = 8.7 cm/s; length of plate = 18.6 cm; thickness of plate = 0.32 cm; Reynolds number based on plate length = 16,200; Reynolds number based on plate thickness = 276; scale seen at left has 1.0 in. major divisions.

the probe. The results of this experiment with a flat plate differ somewhat from those with rods. The rod experiments indicate that a regular, uniform Karman vortex street in the rod's wake exists only between Reynolds numbers of 50 to 150 (based on the rod's diameter). However, a regular, uniform vortex street is present in the plate's wake at a Reynolds number of 276 (based on the plate's thickness). Figure 3 illustrates the potential of the low-velocity water tunnel for hydrodynamic research.

Acknowledgments

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