THE DESIGN, CONSTRUCTION, AND COMMISSIONING OF THE UNIVERSITY OF OTAGO SWIMMING FLUME

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In 1997 the Human Performance Centre commissioned the only swimming flume in Australasia. The flume is a pumped circulating water channel (like a water treadmill) that allows a swimmer or boat to be propelled against a controlled water current for testing purposes. The design, construction, and commissioning of the flume are the subject of this paper. From the initial concept in 1992, the design, and development project took five years to complete. The final design parameters called for a channel 2.5 m wide by 1.5 m deep with a propulsion system able to deliver a steady uniform flow of 3 ± 0.1 m/s. The flume water temperature is controlled at 28 ± 0.5 °C using an energy efficient heat pump and water quality is suitable for video analysis of both above and below water events.

KEY WORDS: swimming, equipment.

INTRODUCTION: In 1994 the School of Physical Education at the University of Otago opened a new 5000 m^2 laboratory complex to service both research and teaching needs into the next millennium. The conceptual design included a controlled environment laboratory and a circulating water channel (flume). Investigations revealed that purchase of a complete flume would be prohibitively expensive, and so it was decided to pursue a design and build path. Design Power NZ completed a conceptual design and cost estimate for the flume in 1993.

The draft specification for the flume was:

Test Section:	10 m long x 2.5 m wide x 1.5 m water depth;
Water Velocity:	0.3 - 5.0 ± 0.1 m/s with uniform steady flow;
Flow Quality:	Waves <25 mm peak to peak, minimum aeration, and clarity suitable for high speed videography;
Water Temperature:	20 to 32 °C ± 0.5 °C using off-peak energy efficient heating and cooling system;
Work Environment:	Climate controlled work environment to provide comfortable working conditions and avoid condensation; Easy access for disabled users; Large optically correct viewing windows; Emergency stop operated by safety net downstream of test section, and a rigid barrier downstream of the net.

Experience with other flumes around the world indicated that there was great potential for instability in the flume hydraulics, and so model studies of the flow path were undertaken. The required velocity range and dimensions of the open channel translate to a range of Froude number of 0.08 to 1.30. This means that flow above 3.0 m/s is potentially unstable, and that the flow depth must be reduced to achieve higher velocities.

Model studies carried out by Opus International Consultants showed the need to:

1. Divide the circular to square transition at the inlet to the headbox into quadrants to reduce swirl from the propellers;
2. Divide the flow vertically throughout the headbox to guide the flow smoothly into the contraction;
3. Seal the headbox to control the free surface in the channel; and
4. Use a 100mm square by 500 mm deep honeycomb to straighten the flow and reduce the scale of turbulence.

The contraction is a smooth bellmouthed entry, which suppresses turbulence, and reduces velocity non-unifotmity by the square of the contraction ratio. In this flume, (contraction ratio 1.86) the non-uniformities are reduced by a factor of 3.46 and so some turbulence is inevitable. Consequently, the contraction wall design was based on circular arcs rather than potential flow analysis. A deceleration section was required to slow down the flow prior to entering the tail box and pumps, to minimise head loss, and to accommodate the hydraulic jump if the flume operates under supercritical flow conditions.

Model testing indicated a total energy headloss of 2 m at 5.0 m/s between the inlet to the headbox and the exit of the tailbox. Assuming 70 % efficiency this required 372kW total power. Consequently, as a cost saving measure, it was decided to reduce the maximum flow velocity to 3.0 m/s, cutting the total energy head loss to 1.7 m, and the total motor power requirement to 267 kW (3 motors @ 89 kW each).

Pump suppliers were generally not prepared to supply low head high volume pumps "off the shelf" and so Australian Defence Industries in Sydney were contracted to design and model test a custom propulsion system. The model allowed simplification of the tailbox design, determination of the motor power and speed requirements, assessment of the risk of cavitation, and determination of propeller diameter and pitch angle.

CONSTRUCTION: The flume contains 190 tonne of water, with about half elevated in a rectangular channel supported on portal frames 2 m above a basement floor. The structure was required to withstand dead, live, hydrodynamic and seismic loading. Hydrodynamic load design was based on model test results for the flume operating at 5.0 ms^{-1}, while seismic loading criteria were based on recommendations of the New Zealand Society for Earthquake Engineering. The elements of the flume most likely to be adversely affected by seismic loads were the head and tail boxes and the viewing windows.

Corrosion protected mild steel was selected for the whole structure for ease of design and construction. The normally dry structural steel was zinc sprayed after fabrication while the open channel and other elements containing water were coated with high build polyamide epoxy paint applied directly over grit blasted and cleaned mild steel. All the steel components were fabricated in sections able to fit through a 2 m square doorway into the basement of the building. The main contractor, E-Type Engineering of Invercargill, fabricated and assembled the whole structure in the workshop prior to painting and delivery to site for final assembly. A perspective view of the completed flume is shown in Figure 1.

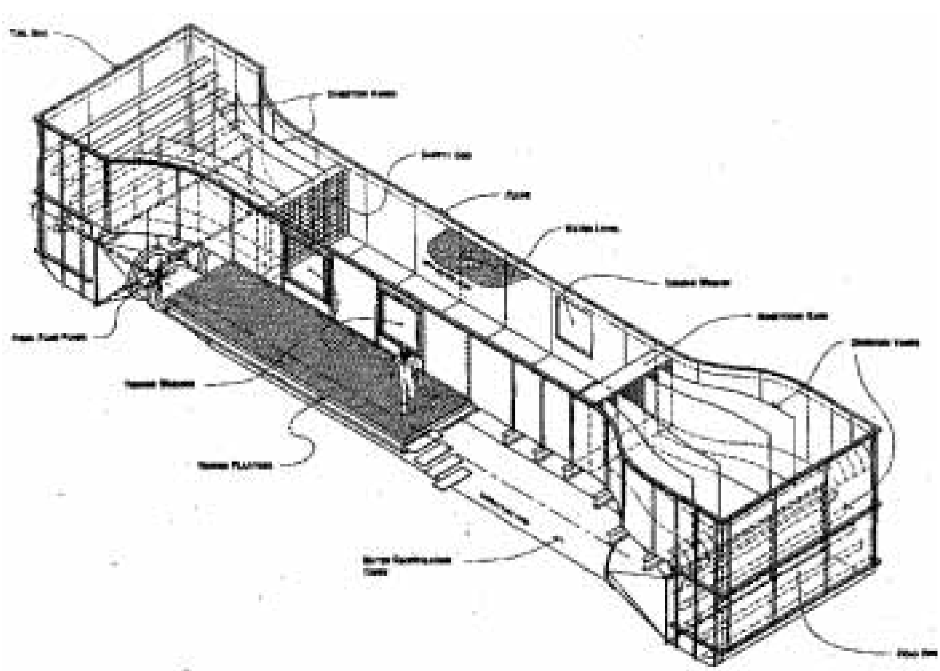


Figure 1 - Perspective view of the flume.

A high efficiency heat pump is used for both heating and cooling to maintain the temperature of the flume relatively constant during use. Water treatment is required to ensure the safety of swimmers using the flume and to maintain the clarity of the water for video motion analysis. Chlorination was avoided because of its highly corrosive nature and so a system using sand **filters** with ultra-violet disinfection and hydrogen peroxide dosing was selected.

Commissioning: The flume was tilled in September 1997. The following tests were carried out to check the operation of the heating, cooling and water treatment plants:

1. Determine the flume **heating/cooling** curve;
2. Check water clarity, pH, and residual H_2O_2 levels;
3. Measure the energy use of the flume and ancillary plant;

The following tests were **carried** out to **determine** the flow characteristics of the flume at 1.5 m depth in the channel.

1. Measure the flow from each propulsion unit;
2. Measure the flow velocity down the channel on the centre line;
3. Measure turbulence levels on the centre line;
4. Determine the velocity distribution throughout the channel.

All flow measurements were done using a Marsh-McBirney model 2000 electromagnetic velocity meter. The unit has a range of 0-7 **m/s**, analog and digital filtering, and an analog output of **0.1V** per **m/s**.

The output of each propulsion unit was measured at **0.6m** depth immediately downstream of the honeycomb. Initially the measurements showed one unit to be significantly different from the others, and so the variable speed drive for that unit was adjusted. Pre- and **post-**adjustment measurements are shown in Figure 2.

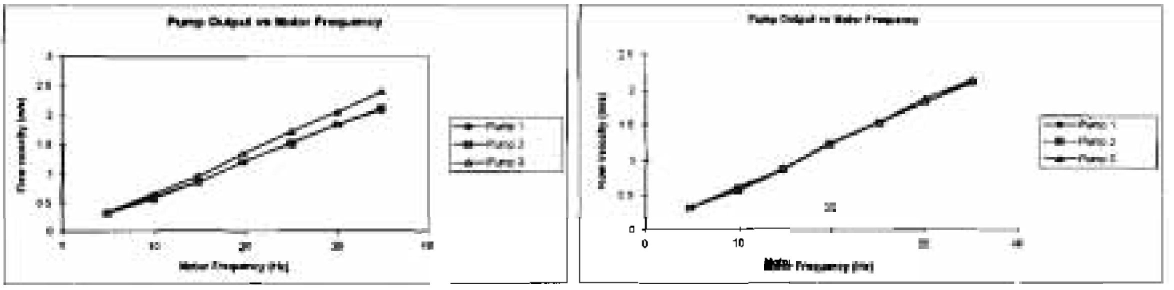


Figure 2 - Individual pump output vs motor drive frequency before and after adjustment of variable speed drives.

The flow along the centre line of the channel was measured at **0.6m** depth at a range of motor speeds. Velocity at distances of I m to **9m** from the honeycomb is shown in Figure 3.

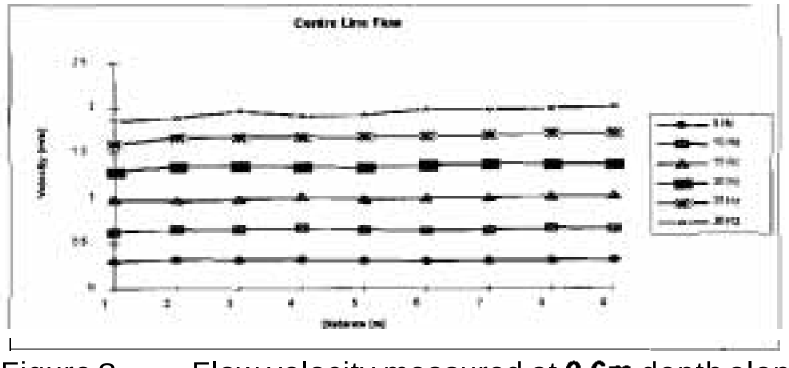


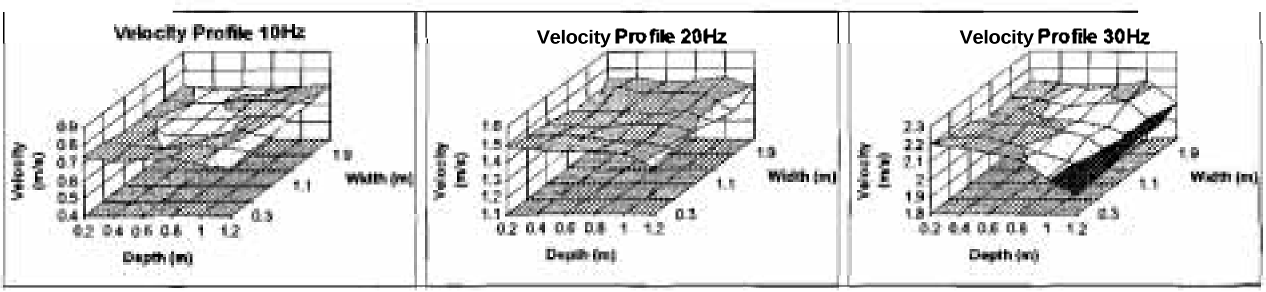
Figure 3 - Flow velocity measured at **0.6m** depth along the centre line.

Turbulence levels were measured at **0.6m** depth, **7m** downstream from the honeycomb. The analog output of the velocity meter was displayed on a digital storage oscilloscope **(HP6200)** which was able to measure both the mean voltage and the RMS variation about **the** mean. The turbulence level was defined as the RMS velocity variation expressed as a percentage of the mean velocity. At a mean velocity of 1.92 m/s, the RMS velocity variation measured over 20 seconds was 0.11m/s, which equates to a turbulence level of 5.7%.

Typical velocity profiles are shown in Figure 4 for motor drive frequencies of 10, 20, and 30Hz at a distance of 6 metres from the honeycomb. Each measurement is an average velocity over 10s. The profiles clearly show that the flow is quite uniform over the majority of the section with some reduction in velocity near the floor and walls. The variation in flow velocity across the section reduces with distance downstream from the honeycomb. The mean velocity shown was measured between 0.7 and 1.9m width and 0.4 and l m depth. Table 1 shows the motor drive frequency and corresponding mean flow velocities at 3m, 6m, and 9m from the honeycomb.

Table 1 Motor Drive Frequency and Corresponding Mean Flow Velocity

Motor Drive Frequency (Hz)	Flow Velocity (m/s) Mean ± SD		
	3m	6m	9m
10	0.700±0.024	0.700±0.017	0.706±0.019
20	1.432±0.042	1.428±0.039	1.438±0.029
30	2.076±0.085	2.083±0.075	2.082±0.073



0.700 m/s 1.428 m/s 2.083 m/s

Figure 4 - Velocity cross sections 6m from the honeycomb at motor drive frequencies of 10, 20, and 30Hz.

CONCLUSION: Further testing and tuning of the flume performance will be undertaken. Present results indicate that the design performance criteria have been met, and qualitative observation indicates that these may be exceeded with further tuning. In the first year of operation there were no operating failures, and the only maintenance carried out was minor touch-up to the paint finish.

Those competitive swimmers and triathletes who have experienced the flume found it a most exhilarating and valuable experience. We have carried out swimming technique modification, and measured physiological parameters including VO_2max and blood lactate concentration safely and easily. It is expected that the flume will facilitate research in aquatic sporting performance in pool and open water swimming, surf lifesaving, and triathlon throughout the Southern Hemisphere.

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