

DESIGN OF SPECIALIST BAROCHAMBERS FOR THE STUDY OF BAROTRAUMA

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Many Australian native fish species undertake downstream migrations, which expose them to passage through infrastructure such as weirs and hydropower facilities. The rapid decompression may cause barotrauma through rapid expansion of their swim bladder and release of dissolved gas in the blood. Specialist, customised barochambers have been designed, built, tested and implemented for the purpose of understanding the upper limits of decompression that Australian fish species can tolerate during passage through water infrastructure. NSW Fisheries researchers have successfully utilised the barochambers to derive mortality and injury versus pressure curves. These specialist barochambers were designed and built at the University of New South Wales. They are relatively large (700mm x 400mm), have large flat glass windows for high speed video of the barotrauma and are capable of achieving pressure changes from up 200kPa to as low as 10kPa in under 0.5 seconds. Further, the barochambers needed to be contained in a mobile laboratory to be taken to various field and laboratory stations. Apart from the rapid pressure changes to incite barotrauma, the chambers could also gradually acclimatise fish to specific pressures over extended periods while circulating water to ensure that dissolved oxygen levels are were maintained.

1 WHY STUDY BAROTRAUMA?

Many Australian native fish species undertake downstream migrations, which expose them to passage through infrastructure such as weirs and hydropower facilities. Fish passing through these structures can be exposed to rapid decompression, causing injuries to the fish through rapid expansion of their swim bladder and release of dissolved gas in the blood. These injuries caused by rapid or extreme changes in pressure are known as barotrauma.

There is a lack of science and a significant amount of uncertainty surrounding the potential impact on native fish of using existing irrigation weirs as proposed mini hydropower generators in Australia. Whilst new technologies are becoming available in the mini hydropower sector, which may provide for safer fish passage, the tolerances of native fish at egg, larval, juvenile and adult stages to passage through mini hydropower plants remains unstudied. Given the vast numbers of fish that have been shown to migrate downstream and evidence that they can be injured as they pass through existing weir structures, research is required to better understand the potential risks associated with new mini hydropower technologies on fish populations. Without this information, it is not possible to make informed decisions on the potential impact on fish populations and the associated social, economic and environmental aspects of proposed hydropower development.

NSW Department of Primary Industries (DPI Fisheries) received funding to study the protection of downstream migrating fish at mini hydropower and other river infrastructure. DPI Fisheries, based at Port Stephens, approached the University of New South Wales, Water Research Laboratory (UNSW-WRL) to design and build barochambers that could simulate conditions encountered by fish during infrastructure passage. Simulation needed to be in a controlled environment and be accurately repeatable for the purpose of establishing mortality or injury versus decompression rates and extremes.

2 DESIGN SPECIFICATIONS FOR AUSTRALIAN BAROCHAMBERS

Two barochambers were required so that experiments could be undertaken in parallel. Each barochamber needed to be 700mm x 400mm x 400mm to allow testing of both larval and adult fish. The barochambers

required large, flat glass windows for photography and fish observation. Access was required through a lockable lid for adding and removing fish.

The barochambers needed to be light and compact to be contained in a mobile laboratory (Figure 1). This allows for the laboratory to be taken on site to locations where fish can be sourced or research staff are located.

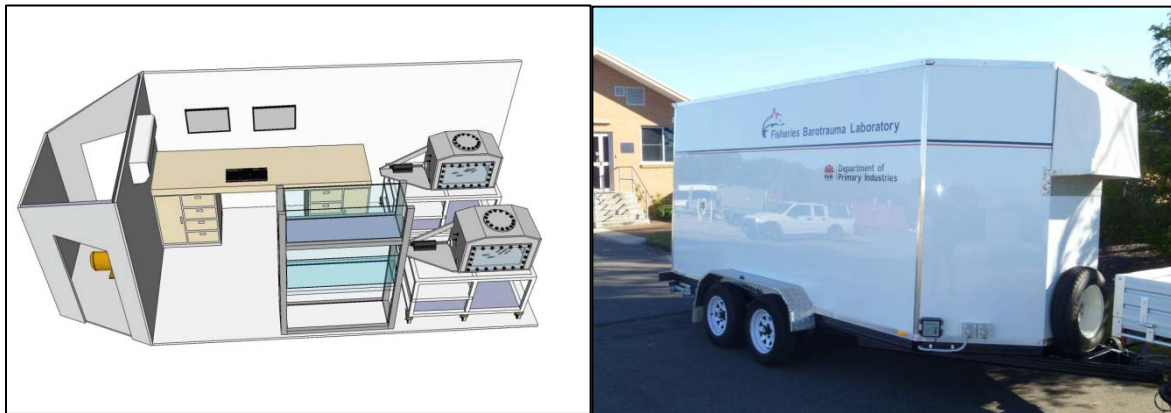


Figure 1 - Schematic and Photograph of The Functioning Mobile Laboratory

Fish needed to be acclimated to specific pressures for extended periods of up to 24 hours before being subjected to pressure changes. This provided adequate time for the fish to regulate buoyancy by adjusting their swim bladder volume. During the acclimation period, water needed to be circulated to ensure that dissolved oxygen levels were maintained.

To simulate hydro-turbine passage for Australian conditions, decompressions as extreme as 200 kPa (absolute) to 10 kPa in under half a second were required in a highly accurate and repeatable way. This pressure range was agreed because it simulates decompression of a fish acclimated at approximately 10 m depth (which is near the highest of any of Australia's inland weirs) to below surface pressure and possible nadir pressures at mini hydropower turbines.

Control software (Figure 2) was required to allow researchers to accurately specify the parameters of the experiment, automate all of the components and record all water pressures and temperatures. This software needed to be intuitive so researchers and technical officers could be quickly trained to run experiments.

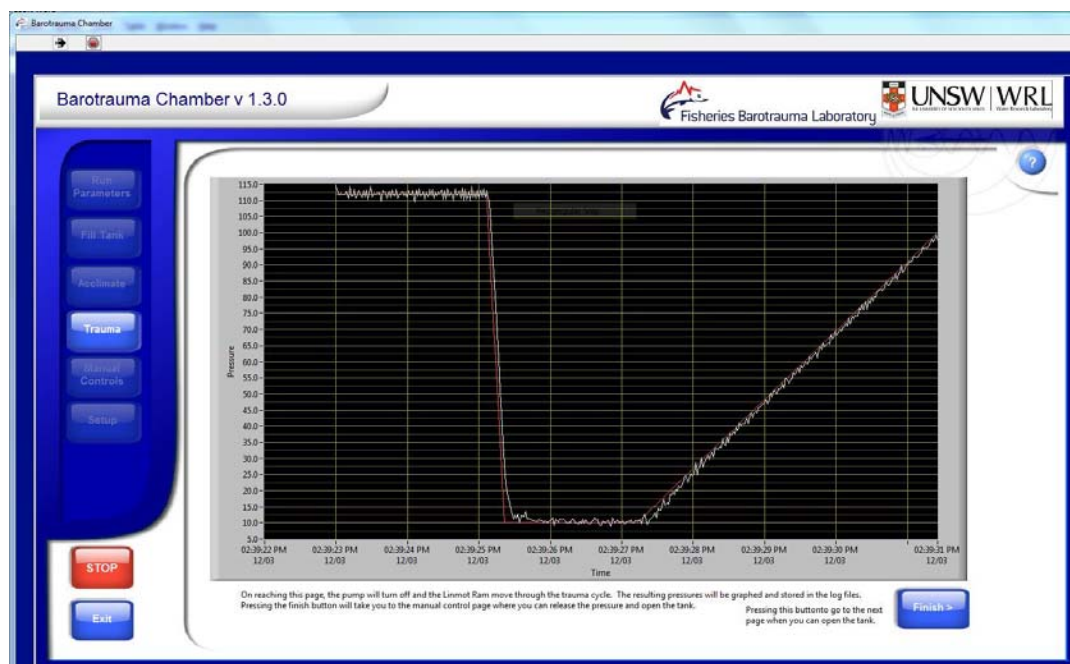


Figure 2 - Screenshot of Control Software

The two barochambers were required to be totally independent systems. This ensured that if operational problems occurred with one barochamber, the other would still be operable. The modular approach also provided greater flexibility for removal of the chambers from the mobile laboratory if this was required in the future.

The barochambers needed to be reliable without complex maintenance requirements. The final, significant design criterion was the budget. The available budget for design, construction, programming and trialling of the two barochambers was approximately AUD\$200,000.

3 FUNDAMENTAL DESIGN CONCEPTS

In order to achieve rapid pressure changes from above to below atmospheric pressure, it is necessary to rely on the compressibility of water to change the pressure. The fundamental concept of the barochamber design is that water is highly incompressible and any change in the volume of the water will result in a corresponding drop in pressure related to the modulus of elasticity of the water. This is described in the following equation.

$$\Delta P = -E \cdot \frac{\Delta V}{V}$$

where P is pressure, V is volume and E is the modulus of elasticity.

The change in pressure was achieved by rapidly moving a piston (Figure 3) into the chamber hence changing the volume. However, the tank walls would change deflection as the pressure changed, so the movement of the piston required an active feedback from measurement of the pressure.



Figure 3 - Fish Awaiting Barotrauma when Piston is Rapidly Withdrawn

4 BAROCHAMBER COMPONENTS

UNSW-WRL designed and built automated barochambers meeting the design specifications. The key barochamber components, their role, the design aspects and implementation are described in the following subsections.

4.1 Tank

Rectangular tanks were constructed from 16mm stainless steel. Lugs were welded into the frame of the tank for attaching the 20mm laminated safety glass. The lid of the tank was removable so that fish could be added and removed at the beginning and end of each experiment. A sloping roof, concave lid and an air release valve ensured that all air could be removed. Air is highly compressible and any air present reduces the performance of the tank.

A rectangular tank has the advantages of better space utilisation and flat windows, but suffers from greater deflection than a circular tank. Minor ($<0.2\text{mm}$) deflections provide significant changes in tank volume when considering pressure changes. As such, the specification of 16mm stainless steel and 20mm glass was to balance weight and deflection, not to meet structural limits.

The tanks were originally intended to have front and back glass windows. However the combined deflections of two glass panels (and rubber seals) were found to be too large to meet the required pressure ranges. As the back windows were not going to be used, these were replaced with a welded stainless steel panel.

4.2 Pump and Circulation System

During an experiment, after fish are added to the barochamber, an acclimation pressure must be reached while water is circulated through the tank to maintain dissolved oxygen levels.

To achieve this, a pump circulated water through the tanks and an actuated ball valve on the tank outlet (Figure 4) allowed fine adjustments to tank pressure. The actuated valve was controlled by an active feedback loop of measured tank pressure. Using this approach, fish in the tank could be acclimated anywhere between 110 kPa to 280 kPa. The design allows researchers to specify the acclimation pressure and the time desired to reach that pressure in the control software.

The maximum pressure head of the selected pump did not exceed the structural integrity of the tanks but a safety valve was installed regardless.

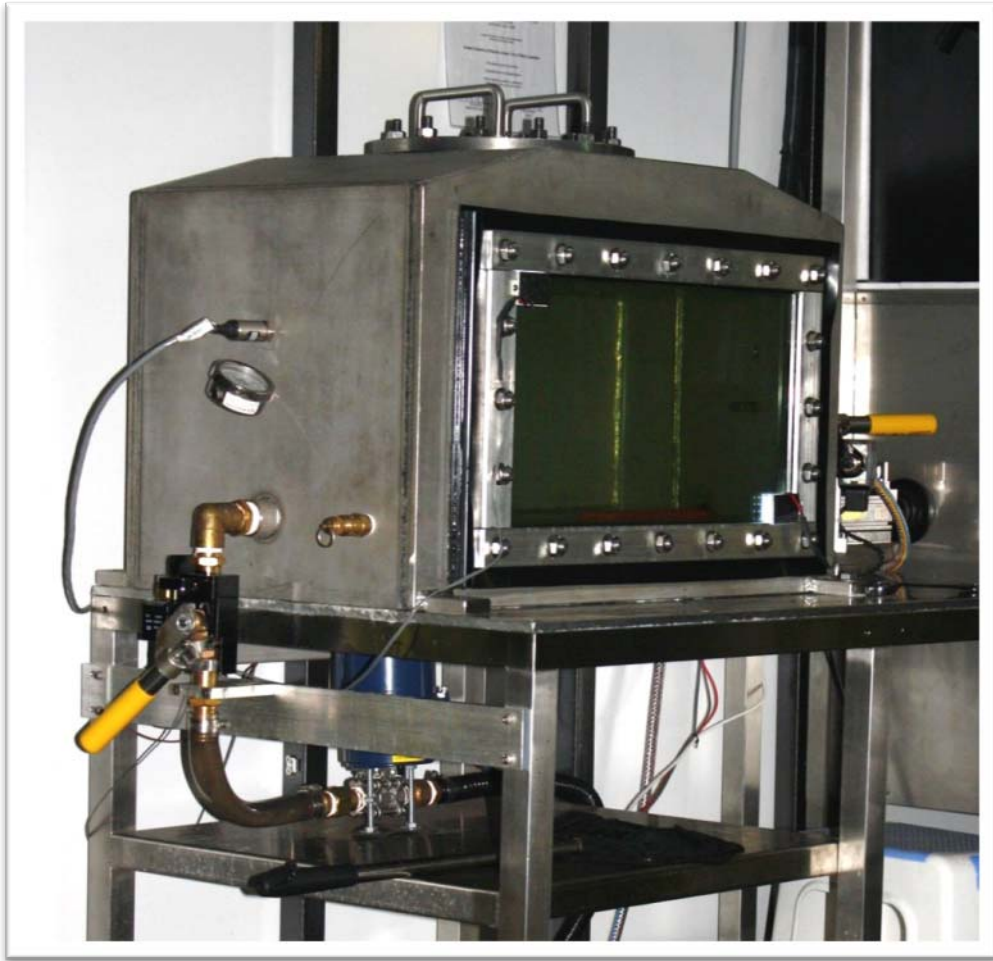


Figure 4 - Tank, Circulation System and Actuator Valve (Below Tank)

4.3 Isolation Valves

The tank must be isolated from the circulation system before the barotrauma sequence of the experiment takes place. UNSW-WRL trialled several types of solenoid valves with limited success due to the range of positive and negative pressures. With only limited electrical power available, UNSW-WRL customised deadman ball valves that would spring shut rapidly (Figure 5). UNSW-WRL designed and added a trigger to each deadman valve so that it could be locked open and “fired” using a small electric solenoid.



Figure 5 - Customised Deadman Ball Valve

4.4 Piston and Actuator

Specific pressure changes in the barochamber were achieved by a piston that was either pushed into or pulled from the barochamber. The piston changes the volume of the water and hence the pressure. This approach raised the design challenge of how to displace a piston rapidly enough, while also being able to overcome forces on the end of the piston. The solution balanced the length and diameter of the piston with an actuator's speed and load rating. The larger the diameter of the piston, the less movement required but also the greater the force needed on the end of the piston. The solution was to apply a 38mm diameter piston to a "Linmot" electromagnetic actuator (Figure 6) capable of moving 300mm in under 0.5 seconds. This actuator met both the power and cost criteria.

UNSW-WRL also needed to build a customised rod seal (Figure 6) that would withstand the pressure ranges while also being near frictionless.



Figure 6 - Electromagnetic Actuator and Custom made Rod Seal

The piston was controlled with by an active feedback loop of measured pressures and target pressures. UNSW-WRL originally trialled a system without feedback where the piston movement would be calculated from pre-determined tank characteristics. However, while this allowed slightly faster pressure changes, it was unsatisfactory in meeting the exact target pressure requirements. The feedback loop (running at 50Hz) with tuned PID parameters ensured that pressures and speeds of change could be specified precisely. Even the variability created by expanding fish bladders was compensated for!

4.5 Control Software and Electronics

The control system is bespoke software written in Labview which controls all instrumentation through a National Instruments interface card. It is simple to use, allowing the operator to define pressure profiles (user-defined time series files) and produce detailed log files of hydraulic performance (Figure 2 and Figure 7). The key instrumentation includes: an electromagnetic actuator to move the piston; two pressure transducers; a temperature thermistor, an actuated control valve for adjusting acclimation pressures; an activated power switch to the pump; and custom made isolation valves. UNSW-WRL manufactured customised electronic circuitry to interface between the control software and the instrumentation.

Tuning of feedback loops between the tank pressure and the piston movement required significant experimentation and software adjustments before appropriate timing and PID parameters were found.

The software has been compiled in Labview as executables without the need to distribute licences. The source code is flexible for future modifications as required.



Figure 7 – Control and Monitoring Software

5 PERFORMANCE

The two barochambers have been in constant use by DPI Fisheries since November, 2012 and have been outstanding in their performance. The mobile laboratory has been used in both DPI Fisheries Narrandera and Port Stephens research facilities.

The project team have succeeded in meeting all of the design criteria. The barochambers are extremely accurate in their ability to meet the desired pressure cycles (Figure 1). The ability of the active feedback loop and piston control to automatically compensate for the number and size of the fish is a remarkable outcome.

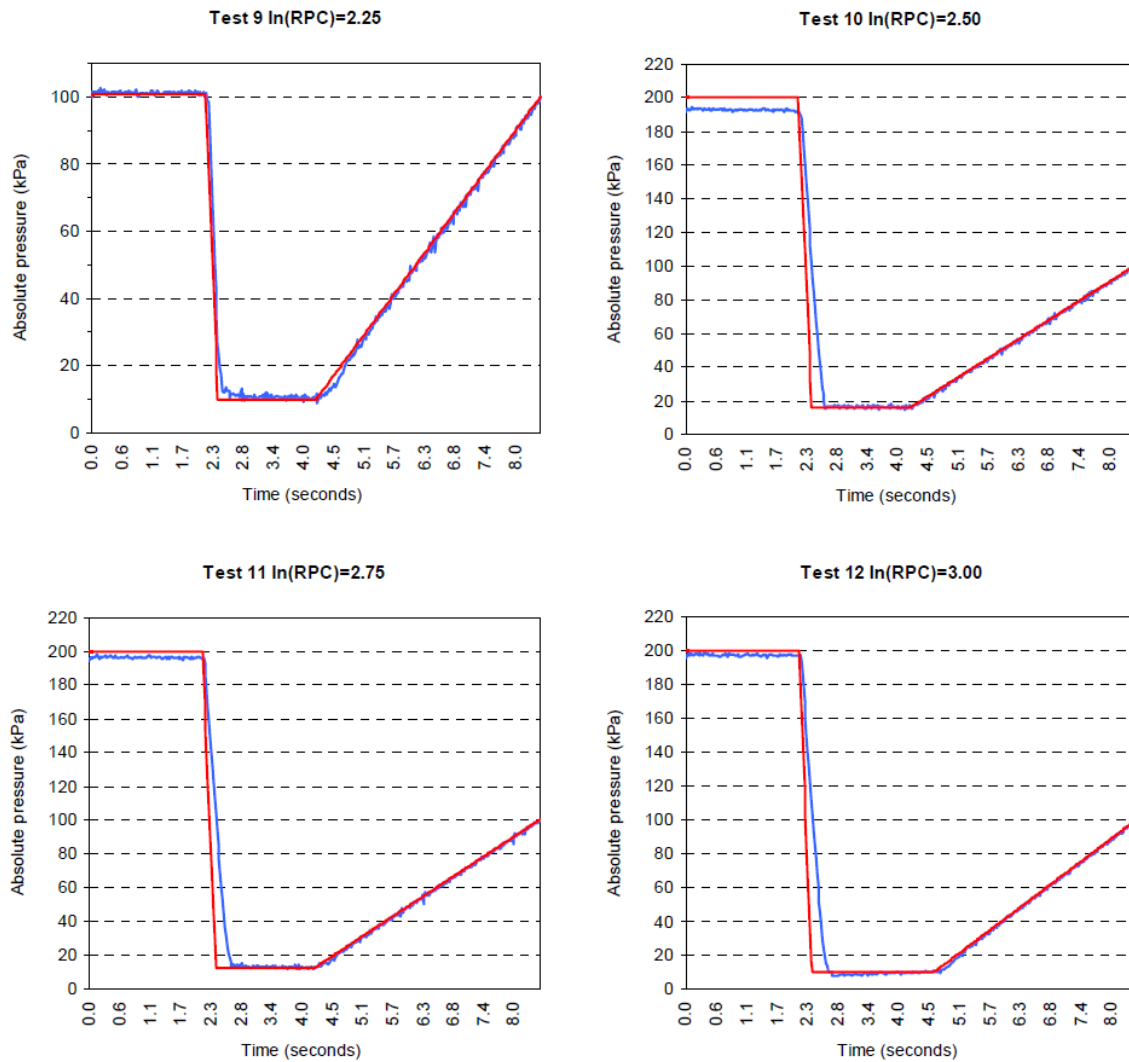


Figure 1 - Sample Graphs of Pressure Change Performance.
(Red line is the programmed pressure cycle, blue line is the measured data.)

6 CONCLUSION

These barochambers are unique in having large flat glass windows; being sufficient in size for large adult and larval fish; having an active feedback from pressure transducers that produces highly accurate and repeatable results; being able to achieve such rapid pressure changes through the compressibility of water; being able to be operated only using electrical power; and having all components fully automated and under the control of customised software. Bespoke, automated ball valves on the tank inlet and outlet overcame engineering constraints experienced with commercially available valves.

The research undertaken using these barochambers will provide guidelines for maintaining environmental protection and directly address issues such as those raised in the Murray Darling Basin Authorities' native fish strategy.

Fish welfare at river infrastructure is a global problem and investment into research and development is required if current fisheries declines throughout the world are to be addressed, whilst investment in emerging energy sectors is supported. Safe passage of fish through hydropower needs to be considered during the construction and approval phase, not as an afterthought.