Water Tunnels

One of the earliest water tunnels and the first constructed for the purpose of successfully studying high

Figure 1: Russell W. Porter schematic of the High Speed Water Tunnel at the California Institute of Technology.

speed cavitating flows was built by Robert Knapp at the California Institute of Technology. With the guidance of Theodore von Karman, Knapp constructed the High Speed Water Tunnel shown in Figure 1 using wind tunnel guidelines but without the deep section shown in that schematic. However, in the initial testing under cavitating conditions in the working section, the water completing the circuit of the tunnel returned to the working section contaminated with a multitude of air bubbles that had been produced by the cavitation in the first through flow. With further circuits the working section fluid became opaque and the tunnel became unuseable. This presented a new challenge for which the wind tunnel experience had provided no guidance. It became recognized that the cavitation formation of vapor bubbles also drew air out of solution into those bubbles and that air did not quickly redissolve when the vapor condensed further downstream. Indeed calculations showed that the water returning to the working section would have to be held under high pressure for some time in order to redissolve the air bubbles. Subsequently Knapp arranged for a team of construction workers to dig a hole $68ft$ deep below the water tunnel (see Figure 1). Then ducting was installed in that hole so that the return flow passed up and down those $68ft$ several time before it returned to the working section. In addition Knapp installed an deaeration system in order to reduce the air content of the tunnel water to levels well below the saturation at atmosphere pressure. These two fixes produced the first facility capable of running for extended periods under cavitation conditions. Subsequently these fixes were installed in many facilities around the world (see Brown 1949). The High

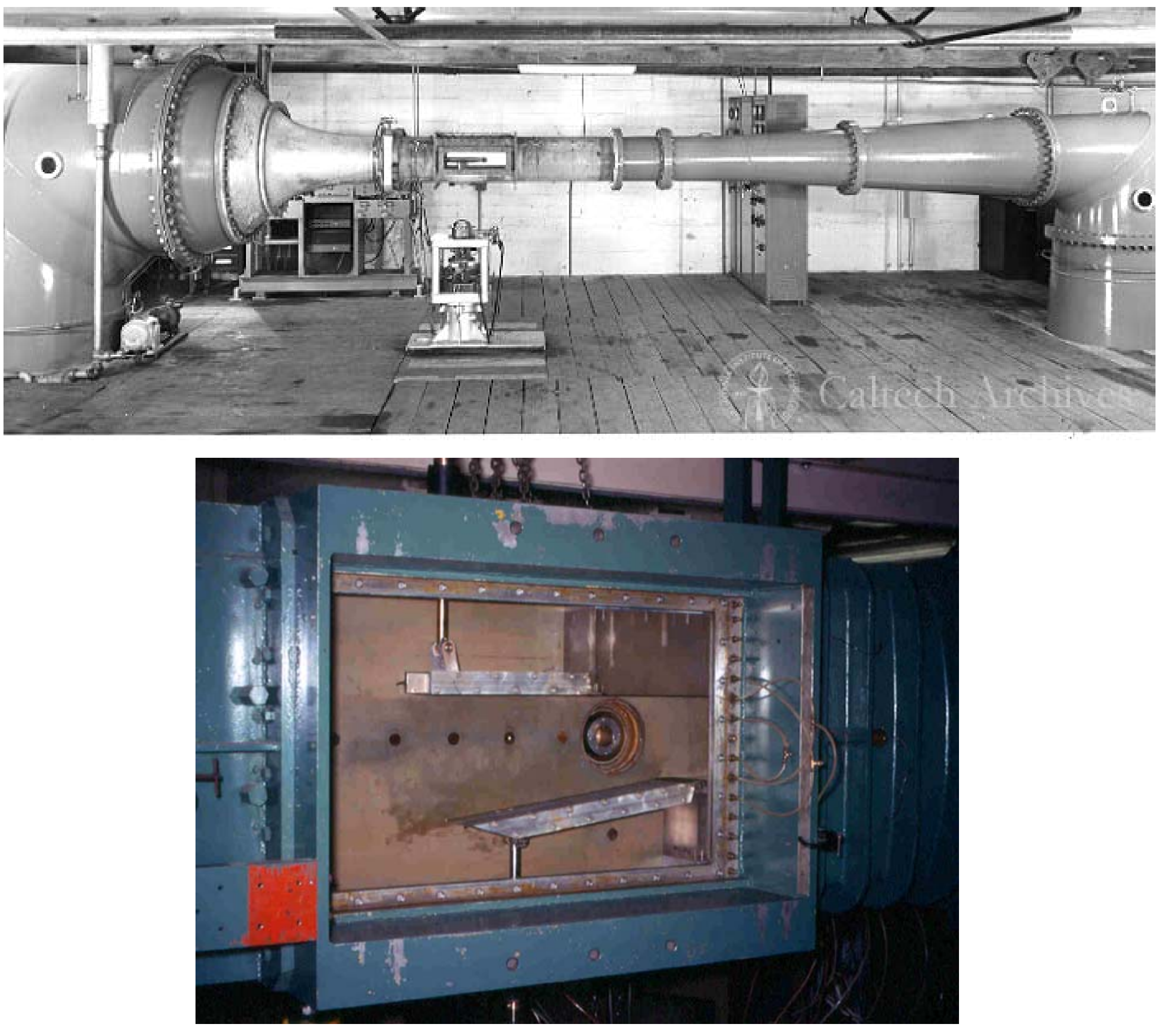


Figure 2: High Speed Water Tunnel at the California Institute of Technology fitted with the circular working section (upper photograph) and with the planar flow working section (lower photograph).

Speed Water Tunnel was also equipped with two alternative working sections, one of circular cross-section used for testing axisymmetic objects and one with a “two-dimensional” working section used for testing hydrofoil designs (Figure 2).

One of the earliest water tunnels was built at the National Physical Laboratory at Teddington (just

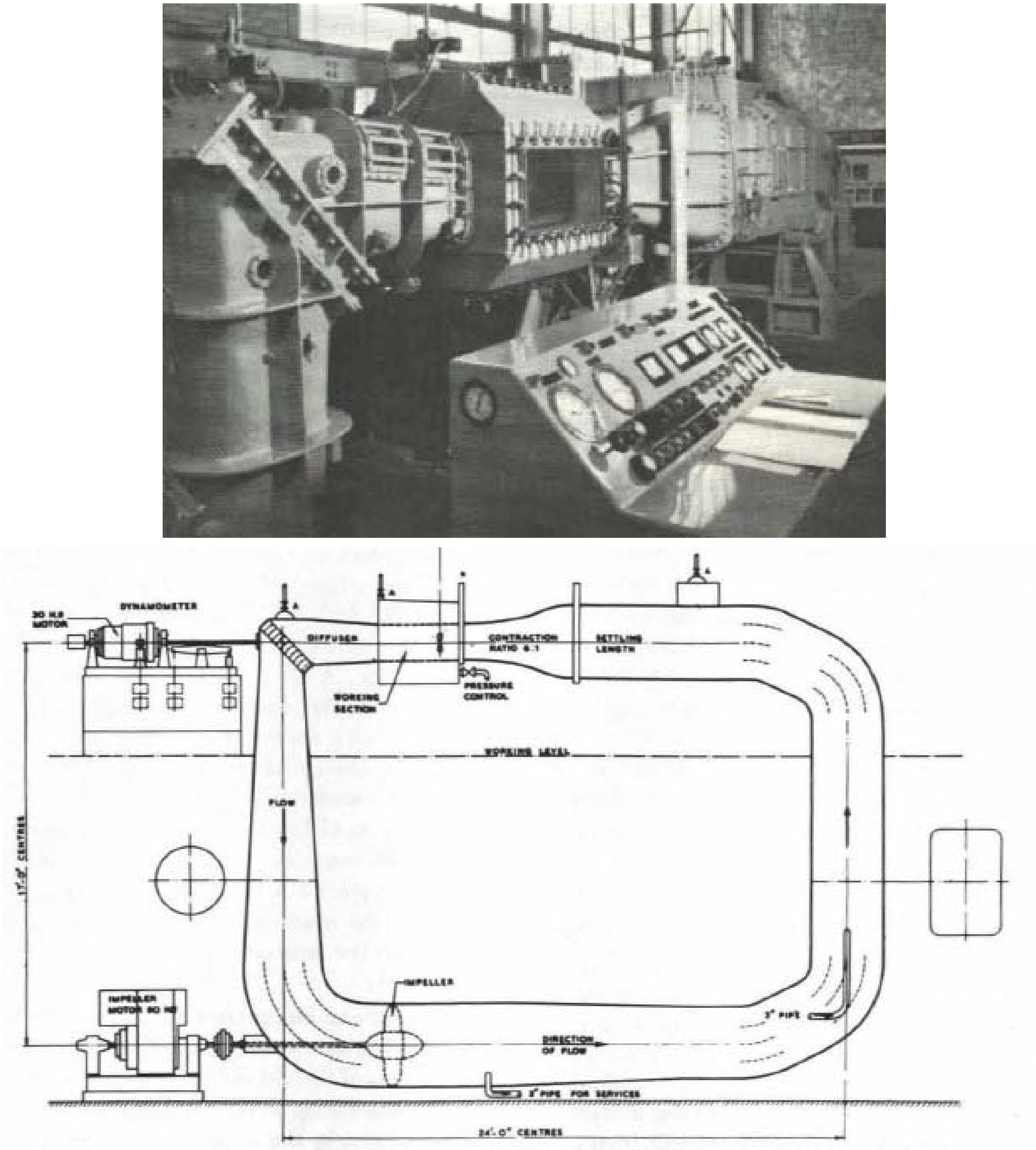
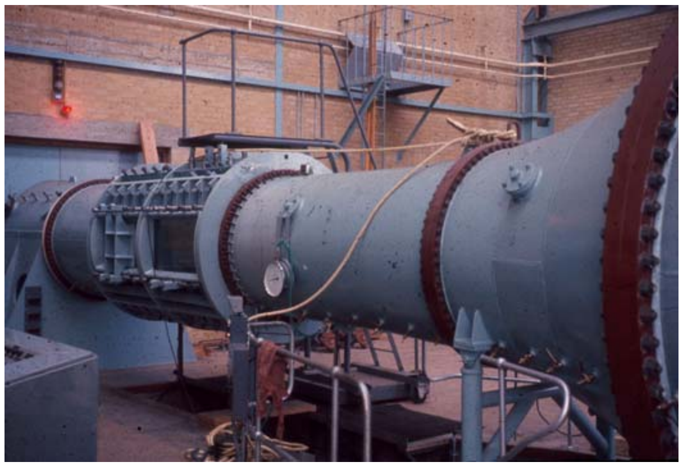


Figure 3: The No.1 Water Tunnel, the Lithgow Tunnel at N.P.L.Ship Division (Feltham).

outside London) in 1932. Known as the Lithgow Water Tunnel, the design reflected lessons learnt in the construction of wind tunnels. As originally constructed in 1932 at Teddington, it had a enclosed working section approximately of $18in$ square cross-section (though with rounded corners) and $30in$ long. Later it was modified to have a slotted-wall working section enclosing a semi-free jet that reduced the wall boundary interference effects of either a solid wall or an open jet (Figure 3). While these and other changes considerably improved the performance of the tunnel, further circuit modifications were made in 1962 when it was the tunnel was transported to the new Ship Division Laboratory at Feltham. The tunnel, which could be run at working section velocities up to about $38 ft/s$, was primarily designed for the testing of propeller performance, including the performance with cavitation. Consequently it was equipped with a water deaeration system that could reduce the dissolved air content for cavitation tests.

A much larger water tunnel was later constructed at the National Physical Laboratory, Ship Division in



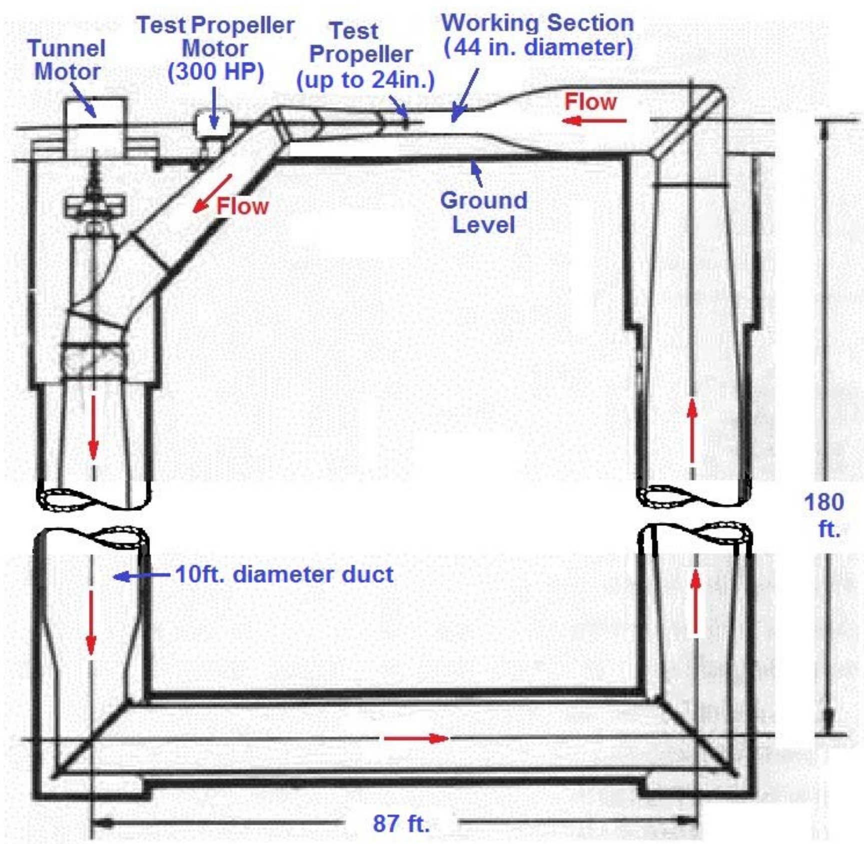


Figure 4: No.2 Water Tunnel at N.P.L.Ship Division (Feltham).

Feltham near London; this facility shown in Figures 4 had a working section of circular cross-section $44 in$ in diameter and capable of velocities of $50 ft/s$. It was originally intended to test model ship propellers up to $24 in$ in diameter at various rotating speeds and various static pressures that would simulate a range of cavitating conditions. In order to minimize the recirculation of air bubbles produced by the cavitation, the return leg of this tunnel was buried $180 ft$below the level of the working section. This facility was demolished during government cost cutting efforts.

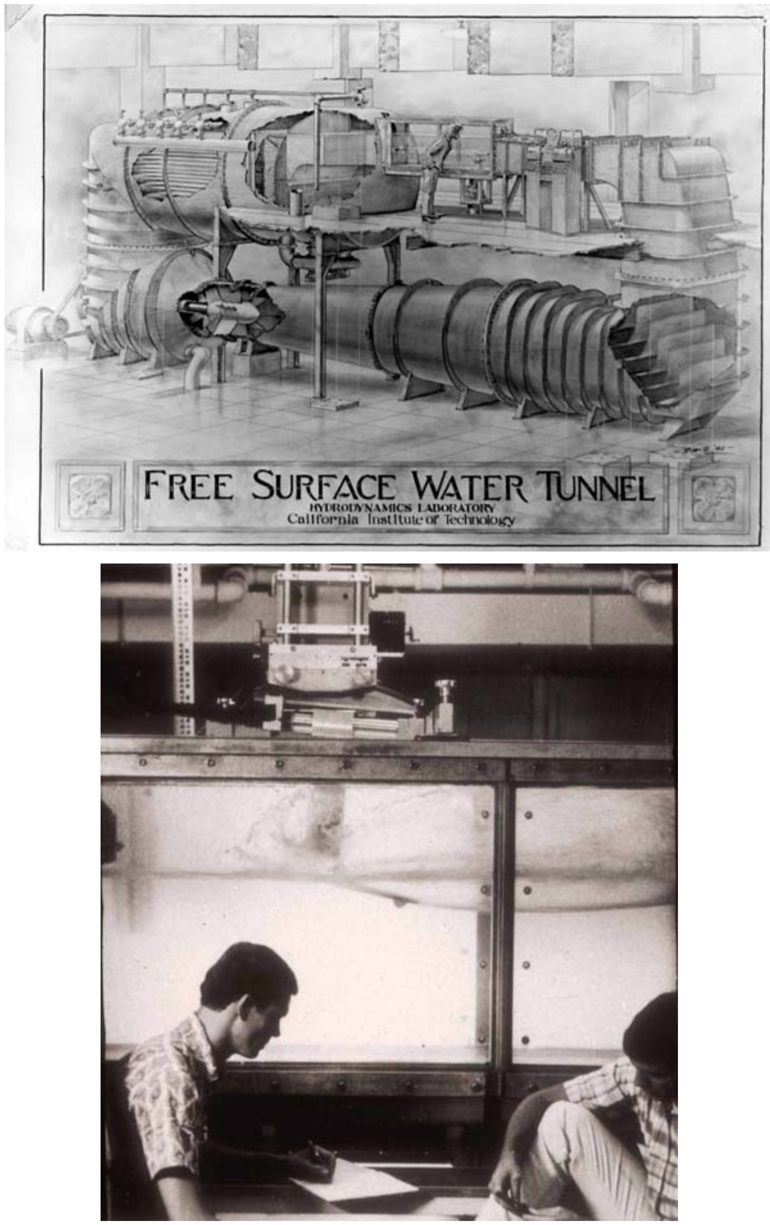


Figure 5: Free Surface Water Tunnel at the California Institute of Technology.

Another type of water tunnel (or water channel) is that with a free water surface. This type is exemplified by the Free Surface Water Tunnel (FSWT) at the California Institute of Technology (Figure 5). Such a design will inevitably have a critical working section speed, U, at a Froude number, $U/(gH)^{\frac{1}{2}}$ (where H is the depth of the water in the working section), of about unity. At that speed, $U \approx (gH)^{\frac{1}{2}}$, standing waves tend to form in the working section and make operation with a flat incoming free surface almost impossible. For the FSWT that critical speed is about $8 ft/s$. The tunnel can be used for low speed flows well below that critical velocity or for high speed flows above up to about $22 ft/s$, for example for surface piercing hydrofoils as shown in Figure 5.

One of the most recent additions to the large water tunnels in the world is the U.S.Navy's Large Cavitation Channel in Memphis, Tennessee (Figure 6). As seen in Figure 6 the $10ft \times 10ft$ working section of this facility has a lid that lifts off to allow installation of test models. It is capable of working section velocities in excess of $38ft/s$.

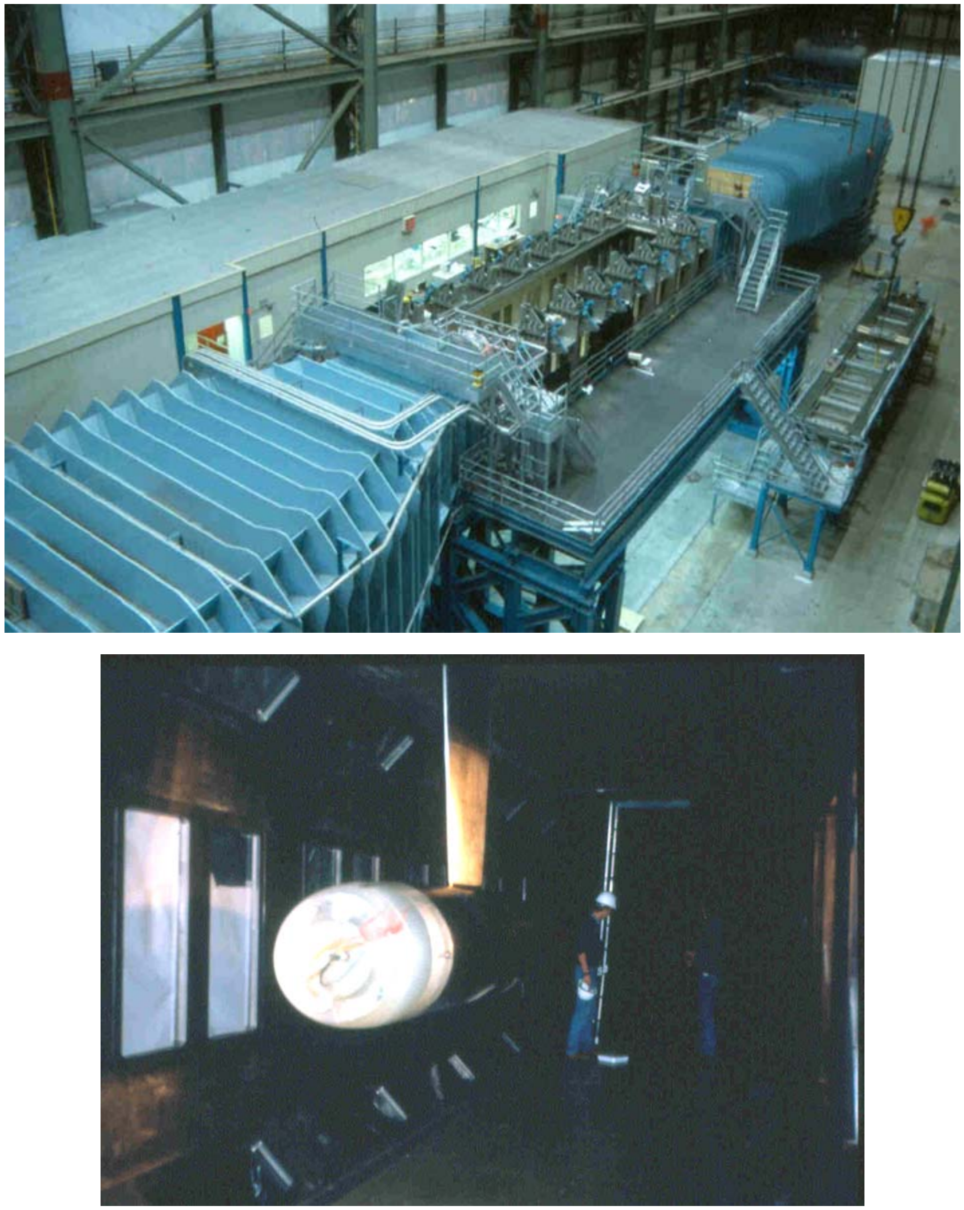


Figure 6: U.S.Navy Large Cavitation Channel. Top: Top view. Bottom: Working section.

A somewhat different class of water tunnel are the facilities used to test large pumps or turbines. We have already described several facilities used to test propellers but there are also some large scale test beds that were designed and built to test pumps and turbines. Turbines, in particular, tend to be large and expensive machines that have merited their own full-scale test beds. An example of such a facility is the turbine test facility pictured in Figure 7.

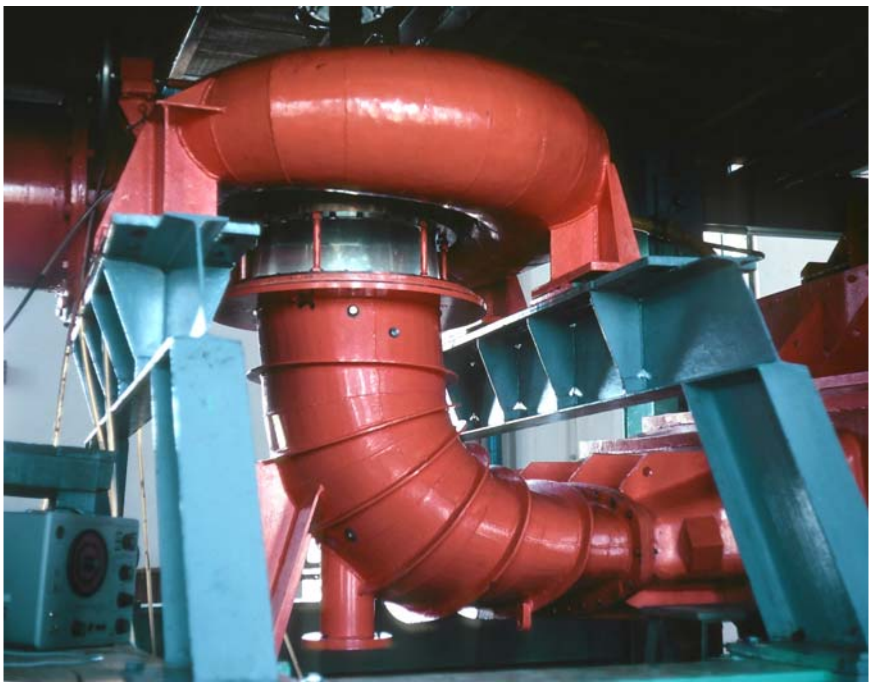


Figure 7: Turbine test facility at the Central Water and Power Research Station (CWPRS) near Pune, India, with a Francis turbine installed.