

# A HISTORY OF THE EMERSON CAVITATION TUNNEL

**Professor Mehmet Atlar**

**School of Marine Science and Technology  
University of Newcastle**

## **Abstract**

The construction and use of the world's first cavitation tunnel by Parsons in Newcastle in 1895, marked the beginning of research into propeller cavitation as well as the science or art of cavitation testing with model propellers. Following the cessation of Parsons' pioneering work the next major landmark in propeller research in Newcastle was the commissioning of the *King's College Cavitation Tunnel* by Burrill in early 1950 within the Department of Naval Architecture of King's College now the Department of Marine Technology of the University of Newcastle.

This paper presents a review of the past, present and future of this tunnel with an emphasis on its rôle in propeller cavitation and related research as well as the education in this field. The review includes the early history and the commissioning of the King's College Tunnel and its transformation to the present *Emerson Cavitation Tunnel* over the ensuing 50 years. A portfolio of major research and development work carried out in the tunnel over this period is highlighted and future prospects for its further utilisation in research and education are discussed.

## **1 King's College Cavitation Tunnel**

Throughout the paper three different titles, which are "*King's College Tunnel*", "*Emerson Cavitation Tunnel*" and "*Newcastle University Cavitation Tunnel*", are used for the subject tunnel. All three titles are associated with the same tunnel such that the first title was used until 1980 when the tunnel was officially re-named as the *Emerson Cavitation Tunnel* following a modernisation work. The latter title is sometimes preferred to associate it with Newcastle University.

### **1.1 Original tunnel at Pelzerhaken**

The roots of the King's College Tunnel are related to an original tunnel at *Pelzerhaken* in Germany, which was dismantled and brought to Newcastle after the Second World War.

The earliest information on the original tunnel was recorded in Burrill's letter to Gawn in 1946 [1]. At that time Lennard Constantine Burrill was the Professor of Naval Architecture at King's College of Durham University, while Dr Gawn was the Superintendent of Admiralty Experimental Works at Haslar. In this letter Burrill expressed his appreciation to Gawn who brought to Burrill's attention the availability of a used closed circulation tunnel in Germany. At the time of this correspondence the tunnel was dismantled from its original site at "*Pelzerhaken*" and waiting for shipment to UK under auspices of British Intelligence Objective Subcommittee (BIOS). In the same letter Burrill

noted the difficulties of converting this tunnel for testing propellers but expressed his eagerness to have it in the university by the following sentence quoted from his letter:

*“I have written to Germany to try to obtain some further information about the tunnel since I feel we should not turn down this offer without going into it as closely as possible as we may not get another opportunity, but from what you say it appears that this tunnel has been somewhat of a white elephant”*. In this quote Burrill described the tunnel as “white elephant” because:

- The original tunnel was not a cavitation tunnel for testing of propellers, but was a horizontally disposed tubular circuit provided with an impeller and motor for circulating the water. This tunnel was fitted with a large rectangular tank, which was used in some way for measuring the absorption of sound radiation when testing through a water circuit at various speeds, and with varying tunnel wall materials.

As sketched in Fig. 1, the tunnel circuit had a separation of 20' (6.1m) and 65' (19.8m) between the centres of its longitudinal and horizontal limbs, respectively. One of the longitudinal limbs, where the observation tank was located, had a rectangular cross section with the dimensions of 0.81m wide and 1.00m deep. The other longitudinal limb, where the impeller was located, had a circular cross-section with a diameter of 1.394m.

- Although the Admiralty Experimental Works and the Royal Naval College were interested in this tunnel, they rejected it because of its horizontal aspect, which would require considerable floor space and it was also no use for propeller tests.

However, at that time, Burrill was already planning to construct a propeller testing facility at the university and he therefore thought that the sections of the Pelzerhaken Tunnel would lend themselves to reconstruction for the purpose of making such a tunnel.

Further support information on the original tunnel can be obtained in a report by US Naval Technical Mission in Europe [2]. Based on this report it can be conjectured that the tunnel was one of the units of the underwater acoustic research complex “*Nachrichten Versuchsanstalt, Pelzerhaken*” constructed in 1938-40. This complex was situated on the shores of the Baltic sea in Lubeck Bay and specialising on underwater acoustic research during the war, involving the inception of cavitation on sound domes, with the purpose of determining the physics of the phenomenon, as well as designing shapes for surface vessel and submarine sound locators. Other work at this complex included the development of a rubber coating for submarine hulls as an anti-locating measure, which could be tested in this tunnel. The development of hydrophones and that of depth charge proximity fuses operating on the Doppler principle for detonation below the plane of operation of an attacked submarine were part of these activities.

More specific information on the original tunnel, which complements the above information, can be obtained in a letter of 1946 and written by the Naval Liaison Officer Lt. Cdr. Ladbroke of British Army of the Rhine in response to Burrill’s enquiry [1]. The letter stated that the institution, in which the tunnel was used as a detention camp and those persons who were intimately connected with the tunnel were no longer there for interrogation at that time. The letter further recorded that the whole tunnel was apparently in excellent condition and was complete with the exception of one sluice gate and mechanism which could be easily re-manufactured. The tunnel was dismantled and was ready for shipment. As far as was practicable, all parts of the tunnel were numbered as they were dismantled and its erection in UK would offer no particular difficulties. This letter was

accompanied by some data sheets and drawings and also particular mention was made to one window in the wall of the tunnel through which observations of measurements could be made. Finally, in his letter the officer asked Burrill to contact the Admiralty in London, if the tunnel should meet his requirements in order that arrangements can be made for its dispatch to UK.

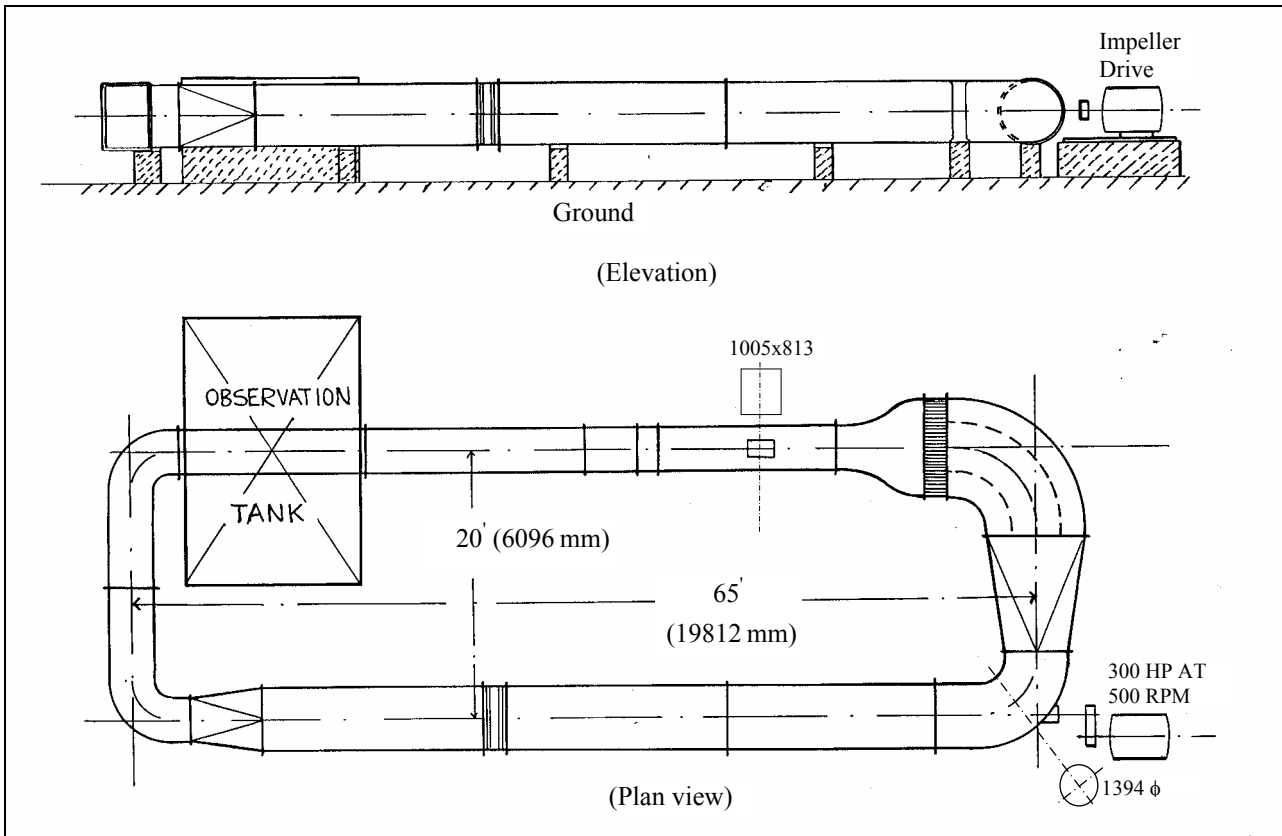


Figure 1 A representative sketch of the original Cavitation Tunnel at Pelzerhaken (1938 –1945)

## 1.2 Shipment of the original tunnel to UK

Burrill arranged the shipment of the dismantled tunnel with Mr SH Taylor of the Admiralty with support from the Rector of King's College, Lord Eustace Percy. The arrival of the tunnel in the UK was recorded in Gawn's letter to Burrill in July 1947 [3].

The transportation of the tunnel was sponsored both by the *Admiralty Experiment Works, Haslar (AEW)* and *Directorate of Scientific and Industrial Research (DSIR)*, now the Engineering and Physics Science and Research Council (EPSRC). Therefore these two organisations were recorded as the first two sponsor bodies which contributed to the commissioning of the tunnel. The parts received in UK included most of the steel tubular sections of the original tunnel, but excluded the large tank which formed part of the original circuit, together with a 300 HP of slip ring type motor generator set which was a first world war German submarine motor. The vacuum equipment listed in the original specifications was not received and only a small reciprocating pump with a cracked cylinder was included.

### 1.3 Conversion plans for the original tunnel

Upon arrival of the tunnel, Burrill approached Messrs. Markham & Co Ltd. Broad Oaks Works in Chesterfield and the local company *Messrs. Vickers Armstrong Ltd. Elswick Works* in Newcastle upon Tyne to take responsibility of modifying and erecting the tunnel as well as to fit a thrust and torque measuring gear for the propeller testing. Although the former of these two companies had the most relevant experience for the task, at that time, they were about to be awarded with a contract from the AEW for the commissioning of the large tunnel which was also brought from Germany. Therefore the contract for the conversion work of the original tunnel to the *King's College Tunnel* was awarded to the local company Vickers in August 1947.

The necessary task for the entire commissioning of the tunnel divided into three parts namely [3]:

- Erection
- Building work
- Provision of new testing gear

It was expected that the proportions of the new King's College Tunnel would be different from the original German design but all the parts were available from the original tunnel. The alteration of two or possibly three lengths of the original tunnel would provide extra portions for the two vertical limbs, and a suitable measuring section. There was a need for the provision of a tank for draining the upper part of the tunnel and the provision of piping for providing a reduced pressure head at the top of the tunnel.

The tunnel was planned to be installed in the Steam Laboratory of the Department of Mechanical & Marine Engineering next to the College Boiler House. This would necessitate some alterations in this laboratory and a superstructure which was to be put over the end of the laboratory and boiler room to cover the tunnel's upper limb as well as providing offices and other work areas.

On the other hand, the provision of new test gear would involve a 150 HP propeller motor with varying speed up to 3000 rpm. This would be combined with the design and manufacture of suitable thrust and torque measuring gear. There was also need for stroboscopic lighting, pitot based flow measuring devices, suitable glands and bearings, as well as suitable windows in measuring sections and some additional guide vanes in corner sections. Finally a vacuum pump arrangement was required to be able to reduce the pressure over the top of the tunnel.

In his early speculations, Burrill envisaged a maximum tunnel flow speed of 10 m/s and made remarks on the similarity between the proposed tunnel and that recently built at the *Ship Building Research Station at Wageningen*. In consultation with Gawn he also envisaged that, if necessary, a 20" (508 mm) or even 24" (610 mm) diameter model propellers could be tested beside a standard size of propeller about 16" (406 mm), considering the large measuring section of the tunnel which was 1.00 m high by 0.821m wide.

### 1.4 Early fund raising for commissioning

*The British Shipbuilders Bronze Propeller Export Group* had a longstanding interest in the provision of a cavitation tunnel to meet the requirements of the propeller manufacturers. Because of his close relationship with the propeller industry, Burrill was able to persuade the three members of

this group, which were *J. Stones & Co. Ltd*, *The Manganese Bronze & Brass (MB&B) Co. Ltd.* and *Bull's Metal & Melloid (BM&M) Co. Ltd.*, to contribute to the commissioning costs of the tunnel. In return, the tunnel would devote some percentage of its services to the testing requirements of these companies.

In fact the early financial support from the Admiralty and the DSIR in transporting the tunnel and the propeller manufacturer's contributions would enable King's College to establish "*The Tunnel Cavitation Committee*", which is described in Section 2.2, to be chaired by Burrill. Under the direction of this committee, the tunnel would allocate 25% of its time to the research for the College while remaining 75% would be allocated for the industry. One third of 75% would be dedicated to the activities for the Admiralty.

### **1.5 Conversion and inauguration of the King's College Tunnel**

From August 1947 until the inauguration of the King's College Tunnel by *Sir Charles Darwin* of National Physical Laboratory (NPL) in June 1949, Burrill went through a tremendous amount of technical and organisational work for the commissioning [3,4]

During this period he continuously consulted his contemporary colleagues in UK and world wide concerning many technical and other issues. Gawn's experience with the Haslar Cavitation Tunnel and his recommendations were instrumental to Burrill in making the final decisions on various technical aspects of the new tunnel. These involved, for example, the decision on the type and power of the model propeller drive unit, the use of the same Ward-Leonard system for the main impeller and the propeller drive unit, the necessity for the measurements of negative torque and thrust and to have a rotating gland where the propeller shaft enters into the tunnel. He further consulted Gawn on the necessity for fine adjustment of the motor speed through an electric control system, the size of the propeller shaft, type of the bracket arrangements and boss caps as well as the use of aerofoil guide vanes at square corners of the tunnel following the practice in the 48" *Water Tunnel at Pennsylvania State College*.

With regard to the necessity of the electric control of the propeller motor Burrill consulted *Prof. Lewis* of *Massachusetts Institute of Technology (MIT)* who used a tuning fork control which was very accurate and cheaper solution, although the system was not implemented in the King's College tunnel.

In selecting an appropriate type of the propeller drive unit and the thrust and torque measuring mechanism, Burrill consulted *JM Ferguson* of *Messrs J Brown & Co Experimental Tank* in Clyde bank, *Messrs Escher Wyss* in Zürich, *Greenwich Naval College* as well as Gawn. The proposed mechanisms included a Ward-Leonard controlled DC drive, a Laurence-Scott AC drive controlled by means of a phase change gear and a rather novel Variable Speed Gear (VSG) drive put forward by Vickers Armstrong Ltd. On the basis of cost a decision was made in favour of the VSG scheme which would require epicyclic gear unit including necessary bearings, torque moment arm and bed plate for the motor and another bed plate for the VSG & epicyclic gear. This measuring gear would allow a maximum thrust of 500 Kp (4903 N) and a maximum torque of 52 Kpm (510 Nm) at a maximum rate of rotation of 2000 rpm and was able to test model propellers up to 20" (508 mm) in diameter.

One of the important aspects of the new tunnel was the electric supply for the main impeller. This was arranged with the local electric supplier *Newcastle & District Electric Lighting Co Ltd*. Based on a continuous running of the tunnel between 8.30am to 5pm and 3.5 days per week (roughly 300kW/year) the estimated running cost of the tunnel was far too high. Burrill did cross check the running period of the tunnel with Gawn in Haslar, Allan in NPL and Troost and van Lammeren in Wageningen who all reckoned that the figure of 300kW/year was excessive for a university tunnel.

The conversion of the original tunnel resulted in the length of the vertically disposed new tunnel being about the half-length of the original circuit and somewhat greater in the vertical dimensions. It was noted that the guide plates in the tunnel elbow were not in the ideal position and required further improvement. Bearing in mind the fact that a considerable portion of the plates would be cut away it was decided to remove the old plates completely and fit new plates into fabrication which was modified to provide a gap for the propeller shaft at the upper limb. The existing observation window was modified and 2 new windows were introduced. The interior of the tunnel was coated by a *bitumastic* material with a bright surface. On inspection of the impeller, it was noted that one of the blades was damaged. Therefore one of the blades was sent to Messrs. MB&B. Co Ltd. to measure the pitch and other details to devise a proper drawing for the impeller. Based on this, the four old blades were replaced by a new set manufactured by this company.

While the conversion was being completed at Elswick Works, the foundation work for the installation was started next to the Boiler House of the College in October 1948 and the tunnel was erected in early 1949. Following the erection the necessary equipment for the flow speed measurements (pitot tubes and differential manometers), tachometer, stroboscopic lighting equipment and contactmeters, and a 3HP vacuum pump had to be provided. Because of the long purchasing time for some of this equipment and the pressure of time for earlier planned inauguration in June, temporary devices were manufactured at the Physics Department of the College in the case of some of this equipment. The electricity supply was available in March 1949.

## 1.6 Early technical problems and calibrations

From March 1949 until the end of 1950, the new tunnel experienced various unexpected early technical problems and went through major calibration work, for the tunnel flow velocity and the propeller thrust and torque measuring gear [4].

For example the tunnel window had to be replaced with a suitable *perspex* acrylic sheet with the dimensions of 24" x 18" x 1.5" (610mm x 457 x 38mm) due to crack in the inner layer of the existing glass and air leakage caused by the pressure alteration. In order to improve the flow through the measuring section and other parts of the circuit various splitter vanes were introduced in the area behind the impeller, in the rapid expansion below the upper floor and on the centre line. A small hat about 15" (381mm) high on top of the coaming was introduced to provide a slightly increased head over the tunnel and, other holes were cut in the three main splitters in order to facilitate the rise of air bubbles.

In order to test the propeller measuring gear, the AEW permitted the use of their 15" (381 mm) diameter model propeller. During these tests it was reported about large frictional losses which required long running duration of the gear in idle condition. The problem was eventually solved by the use of a single spherical self aligning roller bearing for the propeller drive instead of the existing arrangement which had two separate bearings, and that of a special lubricant.

With the new impeller setting, maximum tunnel water speeds of 24 ft/s (7.3 m/s) and a 18 ft/s (5.5 m/s) were achieved for the ahead and astern conditions, respectively, requiring 270 HP (201 kW) at the highest pitch setting. The air content measurements of the tunnel water were made using the Winkler system. Although the stroboscopic lighting was found to be adequate, a second lamp was made to be used from another angle to get a better illumination of the model.

Figure 2 shows the general arrangement of the King's College Cavitation Tunnel.

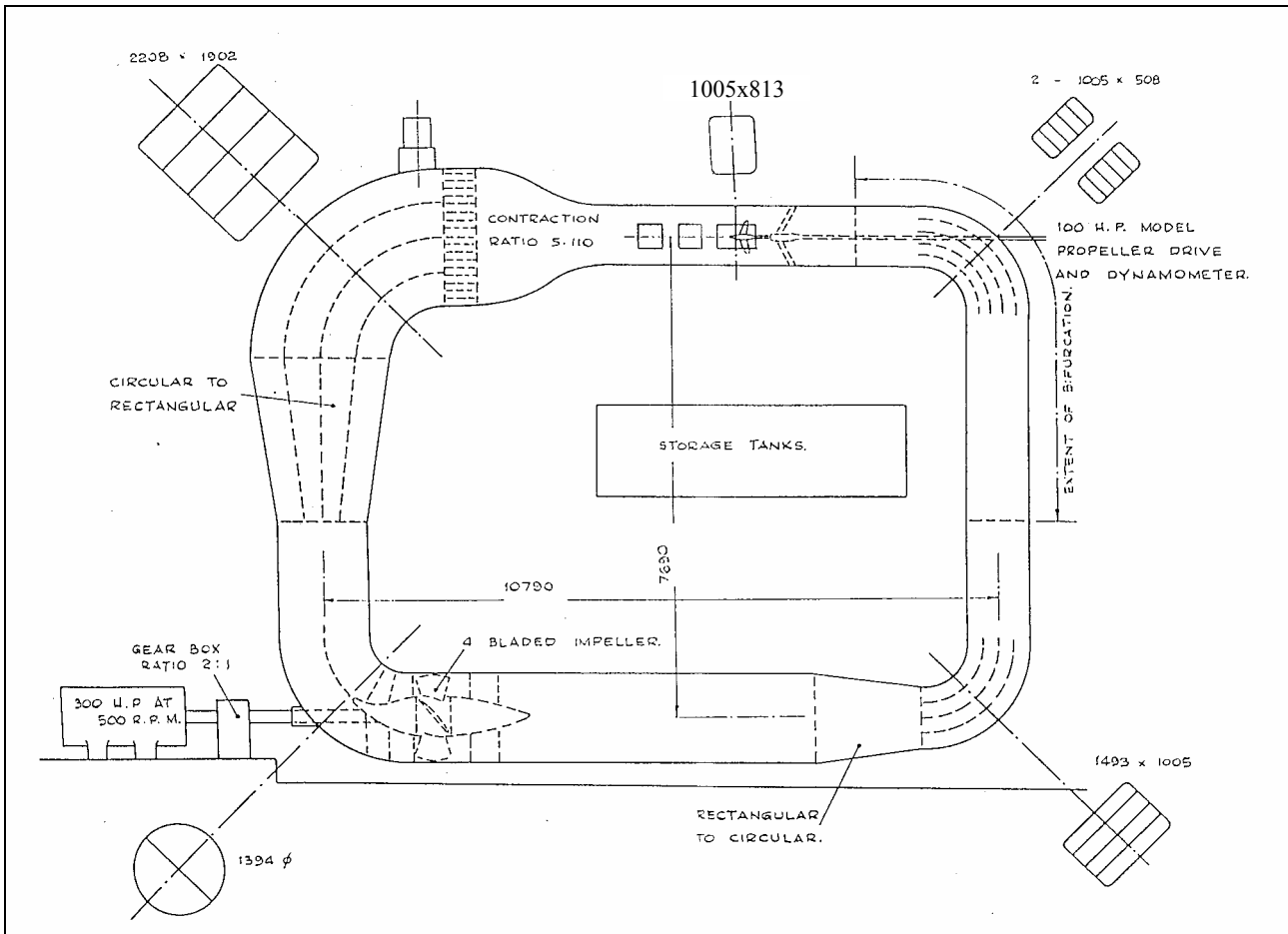


Figure 2 General view of The King's College Cavitation Tunnel (1949-1979)

### 1.7 First research contracts

Encouraged by the Rector of King's College, Lord Eustace Percy, Prof. Burrill applied to DISR for a special research grant, for a systematic series of propeller testing in King's College Tunnel in April 1949. However this application was unsuccessful with a recommendation that its resubmission would be considered, if the new proposal was a joint one involving NPL. Burrill resubmitted the revised proposal to test a new series of some 30 propellers in the new tunnel and NPL towing tank. These propellers would have blade section of the "uniform velocity" type but suitable for merchant ship propellers. In January 1950 this application was approved with the

allocation of £8,000 for 3 years of research work. The expenditure was to be chargeable against staff, special equipment, running costs and other items to be approved by the DSIR.

In the mean time, *The Director of Naval Construction, Department of the Admiralty* placed two contracts with the new tunnel entitled: Propeller Design (Performance) and Propeller Design (Propulsive characteristics) [4]. The former of these contracts involved an investigation into the effect of the shape of the fairing cone on the performance of a model propeller, through 6 different cones. The total budget of this project was £929 and would be completed in 6 months. On the other hand the latter contract was to investigate the propulsive characteristics of a methodical series of propellers, consisting of some 30 propellers to be tested at 6 cavitation numbers. The models would cover  $P/D=0.6$  to  $2.0$  with  $B.A.R.=0.5$  to  $1.1$  all to be of  $t/c=0.045$ . These tests would form part of a comprehensive series which had been in hand at Admiralty for several years. The total cost of the project was £7,000. and would be completed in 2 years. Indeed this project would generate the well-known "KCA" or "Gawn-Burrill" systematic series and associated data.

On the other hand the propeller manufacturers had also drafted a proposed field of research activity, covering the initial 3 years of the tunnel time, starting from March 1950. In this programme it was recommended that the time available should be used for research into: Aerofoils; systematic propeller series; controllable pitch propeller; testing of special designs; and testing of new inventions.

### **1.8 First tunnel personnel and the cavitation tunnel committee**

The first appointments for the newly built tunnel were made in February 1950. They were *Dr Arnold Emerson*, who was appointed as the superintendent Research Assistant from NPL and *Mr. AP Hetherington* as the mechanic from Vickers Armstrong Co. Ltd. The appointments continued through 1950 including two more research assistants, *Dr J Lockwood-Taylor* and *AC Lascarides* as well as another mechanic, draughtsman and a clerical assistant.

Alongside these appointments, it was also decided to establish a tunnel committee of technical experts which would advise the college on the operations of the tunnel. In January 1950 the College Council ratified this committee which would have 3 members nominated by the propeller manufacturers and 3 members by the council of the College under the chairmanship of the Professor of Naval Architecture [5]. The college members of the Committee were *Prof. Sir Thomas Havelock*, *Mr SS Cook* and *Prof. Burrill* who was the Chairman. The 3 members representing the propeller manufacturers were *Mr F McAlister* of J. Stone Co. Ltd., *Mr L Sinclair* of MB&B Co. Ltd and *Mr JF Tucker* of BM&M Co Ltd.

### **1.9 Commissioning and running costs**

Based on the best of knowledge available in the records, the total cost of the commissioning was around £20,000 including the conversion, installation, building costs and equipment. Some £5,500 of this cost was met by the three propeller manufacturers, while the balance was subsidised by the King's College Grant Committee [5].

The running costs of the tunnel were planned to be met by the prospective research contracts from the Admiralty, industry and DSIR. The manufacturers would be prepared to meet up to a maximum



of £5000 in any financial year, for the difference between the cost of operating the tunnel and income received by the College. The annual running cost of the tunnel was estimated to be around a maximum of £10,500 and a minimum of £5,000 in those days.

## **2 Emerson Cavitation Tunnel**

From its establishment in 1950 until the major modifications in 1979-80 the King's College Cavitation Tunnel contributed to the advancement of the propeller technology through a number of important research and development activities. These provided vital information to supplement the rather inadequate early propeller and cavitation theory and the propeller manufacturer's limited full scale experience. During this period, particularly until mid-60's, cavitation was a great obstacle in the design of propellers for high powered vessels with multi-screw propellers at high speeds and relatively uniform flow into propellers, e.g. in passenger liners, ferries and warships. The tunnel therefore was occupied in providing a great deal of basic cavitation tunnel data for these cases as will be summarised in section 3.1.1.

### **2.1 Reasons for modifications to King's College Tunnel**

With the rapid increase in merchant ship size and in the power transmitted on a single shaft, the above nature of the cavitation problem in propellers was replaced with that of the heavily loaded propeller operating in an extremely non-uniform wake caused by the fuller single screw hullforms. This trend required tunnel tests, initially, with the use of transverse wake screens. These tests, which involved the measurements of propeller forces, the observations of cavitation and the erosion measurements using soft surface coatings, were carried out satisfactorily in the King's College Tunnel.

However, further requirements for the generation of three dimensional wake flows and the measurement of hull surface pressures meant that it was necessary to place in front of the model propellers either, ideally, complete and properly scaled hull models or hull shaped bodies referred to as "*Dummy Hulls*". This would require either a new testing facility or major modifications to the existing facility. The cost of such a facility would be much higher than the existing tunnel in terms of the initial costs, operating costs and the personnel costs. In addition to this requirement consideration was given to the satisfaction of the free surface condition or the conduct of experiments at sufficiently high Reynolds number

It was decided therefore that although a national comprehensive facility was then, and still is required, the existing tunnel had to be modified to allow hull-shaped bodies to be placed forward of the propeller as well as to modernise the ageing tunnel machinery and equipment after 25 years of continuous use [6].

### **2.2 Modifications and Emerson Cavitation Tunnel**

The modification work commenced in March 1979 and was completed in 1980. At the official opening ceremony in September 1980 the tunnel was named "*The Emerson Cavitation Tunnel*" after Dr. Arnold Emerson, who was retired by then, for the recognition of his sterling efforts as the superintendent of the tunnel as well as for the driving force behind the modification work.

The modernisation of the tunnel was sponsored by a substantial grant from *The Science Research Council (SRC)* and an equal sum jointly from the University School of Marine Technology and Stone Manganese Marine Ltd.

The modification work was carried out to an extremely tight budget, which was also the case for the old tunnel, due to limited financial resources of the University for such a specific investment. There was further modernisation work and some equipment that it was wished to include but which had to be omitted or put back as a low priority due to this reason. Nevertheless, tremendous in-house effort from the Department and local companies was put into the essential work.

Although only a brief summary of these modifications is given in the following, major design and analysis work had to be carried out concerning the improvement of the flow, the tunnel structure and the proper selection of new equipment for the new tunnel. These are given in more detail in [7].

As far as "*The Measuring Section*" was concerned, to retain as much as possible of the existing structure, at "*The Slow Speed Corner*" turning the measuring section through  $90^0$  was considered but the width of the measuring section was still insufficient. "*The Horizontal Upper Limb*," where the measuring section is located, was therefore built completely new. This section now has square corners, bigger windows and better access to provide a new cross section of 1.22m width x 0.81m height in comparison to the 0.81m width x 1.02 m height of the old King's College Tunnel cross section. Some 30mm thick plexiglass windows were installed at the two sides, bottom and top of the measuring section, protected from accidental scratching by an outer glazing of picture glass.

The long propeller shaft and dynamometer of the old tunnel was replaced by a new dynamometer unit, which is a Kempf & Remmers H33 type, with a  $90^0$  drive from the top. This dynamometer is used for testing propeller models up to 400mm in diameter, in a uniform stream or behind wake screens. The dynamometer is also fitted with 12 slip rings for the transmissions of signals from a hub dynamometer, used in measuring the blade forces of controllable pitch propellers. The H33 dynamometer measures a maximum thrust of  $\pm 2943$  N (300 kp) and a maximum torque of  $\pm 147$  Nm (15 kpm) over a speed range of 1000 to 4000 rpm, with a 300mm diameter of model propeller used as a standard. The DC current to the dynamometer drive motor was supplied by a 65kW thyristor controlled converter.

At "*The High Speed Corner*" the removal of the old propeller drive and its associated split hydraulic circuit allowed a greater expansion and so more reduction in water velocity between the end of the measuring section and the high speed corner. An entry to exit ratio of 0.655 was achieved with the new diffuser section, which was expanded at the bottom and sides, following the measuring section. The circular bend of the old tunnel at the high speed corner were replaced by a  $90^0$  mitred corner with 13 turning vanes with adjustable setting.

While "*The Lower Horizontal Limb*" with its various supports and connections were kept as original due to the budgetary considerations "*The Downward Flow Limb*" had a square cornered rectangular cross section length at the top and a transitional length at the bottom. Similar to the high speed corner the top of "*The Rising Flow Limb*" was changed from a radiused corner to the mitred corner, which gave extra length for the expansion, with 16 new vanes. In completing the circuit in the upper horizontal limb to the measuring section length, the original honeycomb was slightly modified. Following the experience with the 48" Water Tunnel at Pennsylvania State College, a

new contraction ratio of 4.271 was achieved in comparison to a contraction ratio of 5.11 with the old tunnel.

In the design of the measuring section, the adjustment of the contraction and diffuser profiles for the provision of steady flow with no separation and cavitation, required detailed analysis based on Ross et al [8] and Salter [9]. This was supported by the use of an in-house flow analysis software based on the turbine blades in cascade for the detailed flow analysis through the blades to provide minimum risk of cavitation and separation in this section.

Finally the original impeller drive system, which comprised an AC/DC motor generator with exciter, was replaced by a solid state converter unit. In order to achieve the maximum required speed, which is about 8 m/s at the new enlarged cross section, a 30% increase in power was necessary. Therefore a 300 kW DC motor operating at a maximum of 1500 rpm and associated with a gear box of ratio 5.063:1 now drives the impeller. This is also thyristor controlled to allow the setting of both steady and ramped water speeds in the tunnel circuit.

As well as the above modifications, various alterations and improvements to the laboratory area were also carried out. These included a new overhead travelling crane and associated skylight to lift the new dynamometer and various access lids of the measuring section. A new control console for the drive systems and a portable manometer and static head gauge manufactured in the Department's workshop were installed.

Figure 3 shows the general arrangement of the Emerson Cavitation Tunnel while Photo 1 illustrates the laboratory area with the tunnel.

### **2.3 Improvements to Emerson Cavitation Tunnel since 1980**

Since the modernisation of the tunnel in 1980, no other major structural alteration has been carried out on the tunnel itself but the tunnel has been kept in good order through a routine maintenance programme.

However, during this period, continuous improvements have taken place on the essential parts of the operating and the flow measurement systems of the tunnel. These included the purchase of a portable system of equipment for the measurements and analysis of the wake and hull pressures as well as for the acoustic measurements. A second dynamometer, a Kemp & Remmers R45 type was also purchased for testing smaller propeller models behind hull models. This dynamometer can measure  $\pm 687$  N maximum thrust and  $\pm 39$  Nm maximum torque over the same speed range as the large dynamometer.

In parallel to the developments in computer technology the instrumentation, data collection and on-line data analysis of the tunnel have been improved using computer based systems, particularly using the LABview software environment. Although traditional still/moving photographic equipment still available, this ability of the tunnel has been enhanced with the purchase of a high speed CCD video camera (Flashcam) with a fast electronic shutter which can be triggered at any time yielding an imaging frequency of 0 to 50 frames/s.

Although the tunnel is equipped with various flow measuring devices based on pitot tubes and small impellers (Streamflo), the major improvement in this area has been the purchase of the 2-D

combined Laser Doppler Anemometry and Phase Doppler Anemometry (LDA/PDA) system in 1999. This equipment, manufactured by Dantec Measurements Technology, includes a 60 mm diameter 2-D submersible probe with 500mm working distance. It has a Multi-PDA signal processor, 3W water-cooled Argon-Ion Laser and a fully computer driven 2-D traversing system. The whole system is flexible enough to be upgraded for the third component in the future. The funding for this equipment was raised from the EPSRC and other industrial supporting companies, jointly with the Universities of Strathclyde and Glasgow.

As part of the general maintenance programme, the ageing dynamometer drive control and vacuum pump systems have recently been replaced with modern ones. The laboratory area around the tunnel has also been improved and display stands have been installed to exhibit some of the systematic series of model propellers and other interesting artefacts tested in the tunnel over the years.

Table 1 presents a summary of the main features and equipment of the Emerson Cavitation Tunnel at the present.

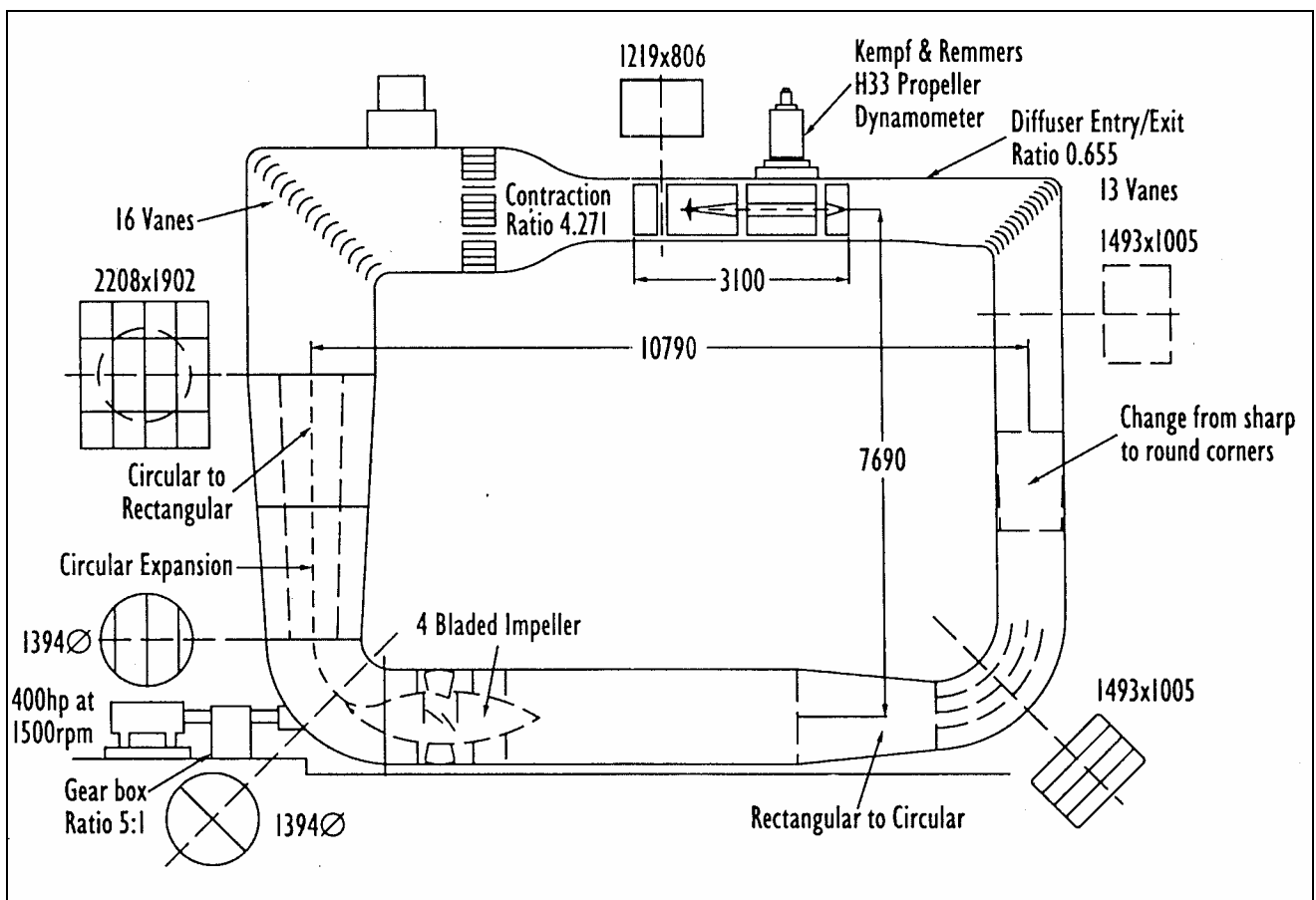


Figure 3 Present view of the Emerson Cavitation Tunnel



Photo 1 A view from the Emerson Cavitation Tunnel and laboratory area

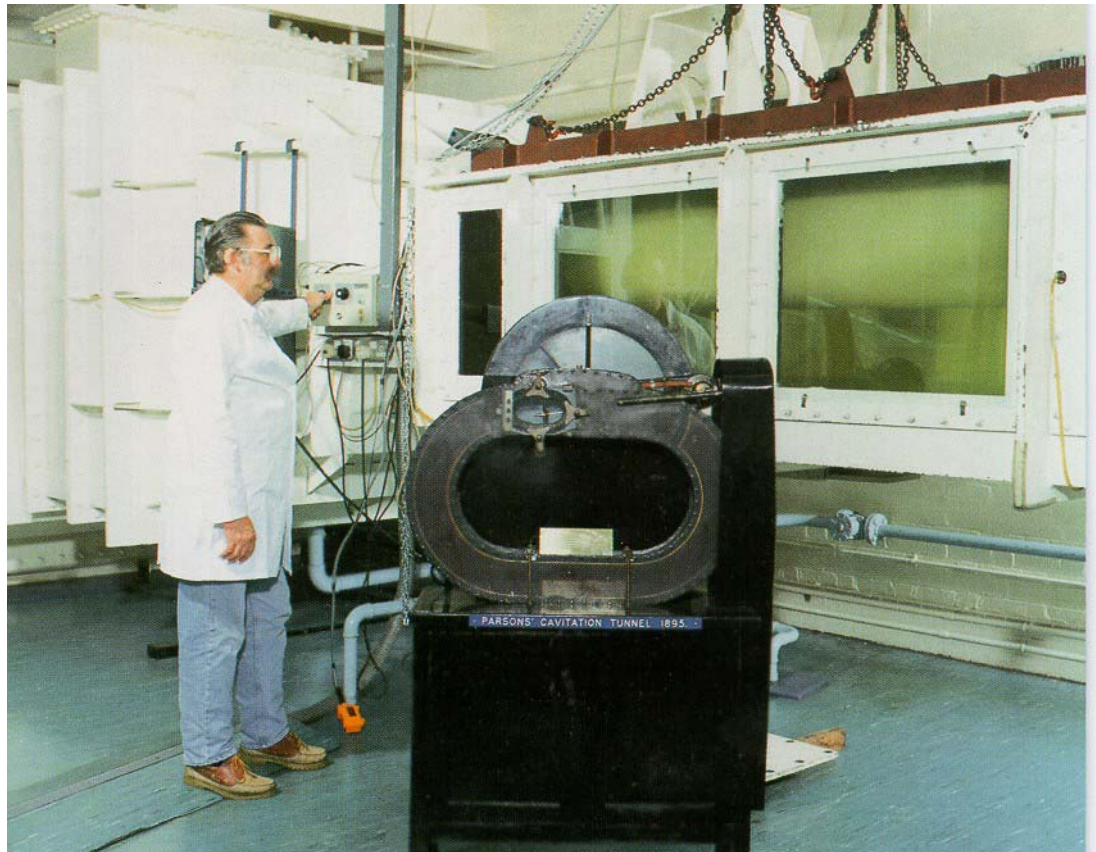


Photo 2 Parsons Cavitation Tunnel standing in front of the Emerson Cavitation Tunnel

Table 1 Main details of the Emerson Cavitation Tunnel

• Establishment year	1949
• Description of facility	Vertical plane, closed circulating
• Test section size (LxBxH)	3.10x1.22x0.81 m
Test section area	0.99 m <sup>2</sup>
• Contraction ratio	4.271
• Type of drive system	4 Bladed axial flow impeller with thyristor control
Main pump power	300 kW
Main pump rotational speed	294 rpm
Impeller diameter	1.4 m
• Maximum velocity	8 m/s (15.5 knots)
• Absolute pressure range	7.6 kN/m <sup>2</sup> (min) to 106 kN/m <sup>2</sup> (max)
• Cavitation number range	0.5 (min) to 23 (max)
• Model propeller size	150 mm to 400 mm depending on the type of test
• Dynamometer type 1	Kempf & Remmers H33 propeller dynamometer
Maximum thrust ±	2943 N
Maximum torque ±	147 Nm
Maximum rpm	4000
• Dynamometer type 2	Kempf & Remmers R45 with vertically adjustable drive system and suitable for placement inside of hull models
Maximum thrust ±	687 N
Maximum torque ±	39 Nm
Maximum rpm	4000
• Laser Doppler and Phase Doppler Anemometry system	Dantec Measurement Technology upgradable to 3-D
Electronics	Multi-PDA Signal Processor
Laser type and power	Spectra Physics, water cooled Argon-Ion and 3W
Probe details	60mm diameter 2-D submersible type with 500mm working distance
Traversing system	2-D fully computer driven with a range of 590 mm x 690 mm
• Acoustics	Bruel & Kjaer 8103 miniature hydrophone and associated instruments