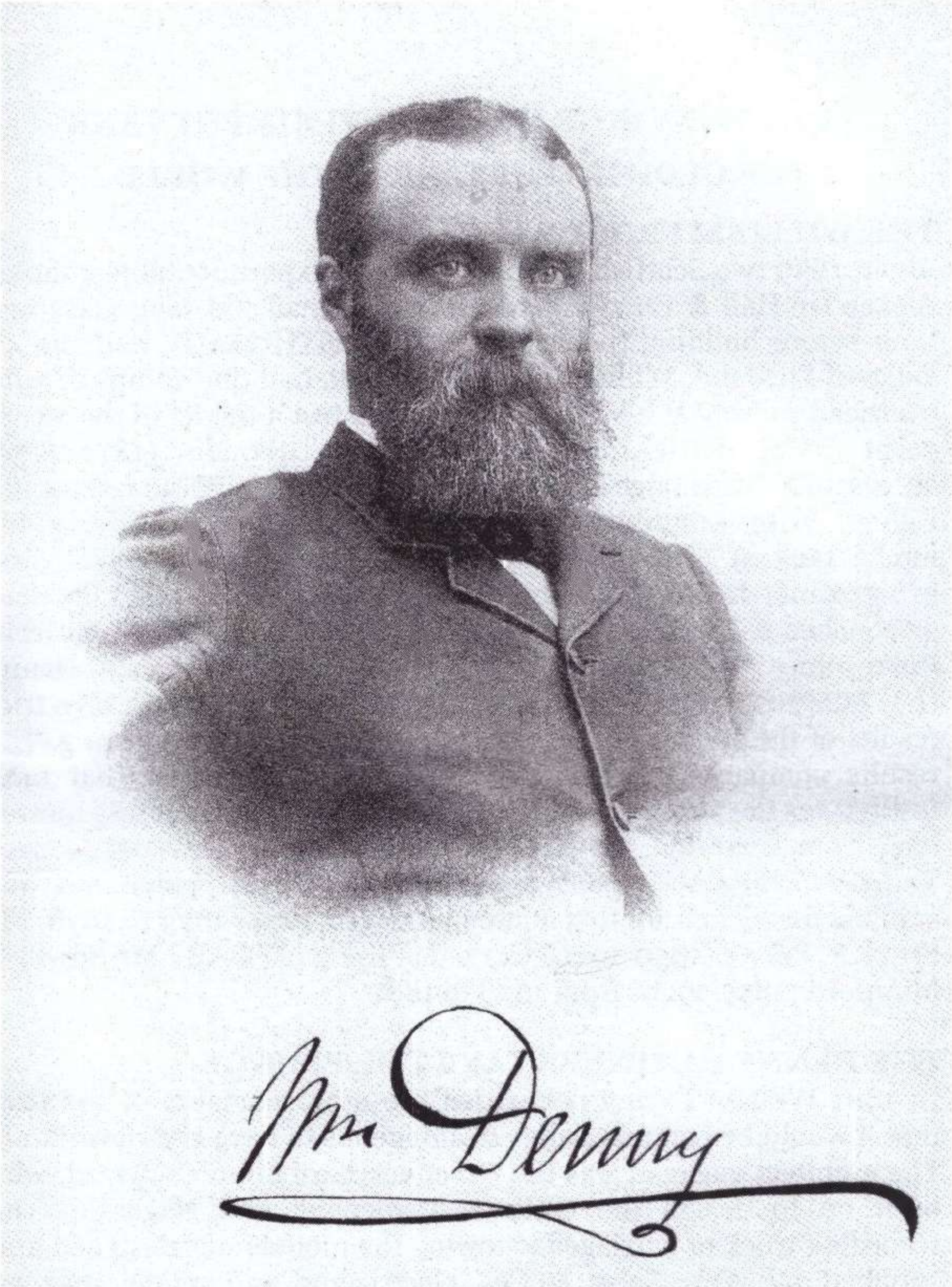
THE DENNY SHIP MODEL EXPERIMENT TANK

THE OLDEST TEST TANK IN THE WORLD

The Scottish Maritime Museum



WILLIAM DENNY (III) [1847-1887]

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THE WILLIAM FROUDE LEGACY

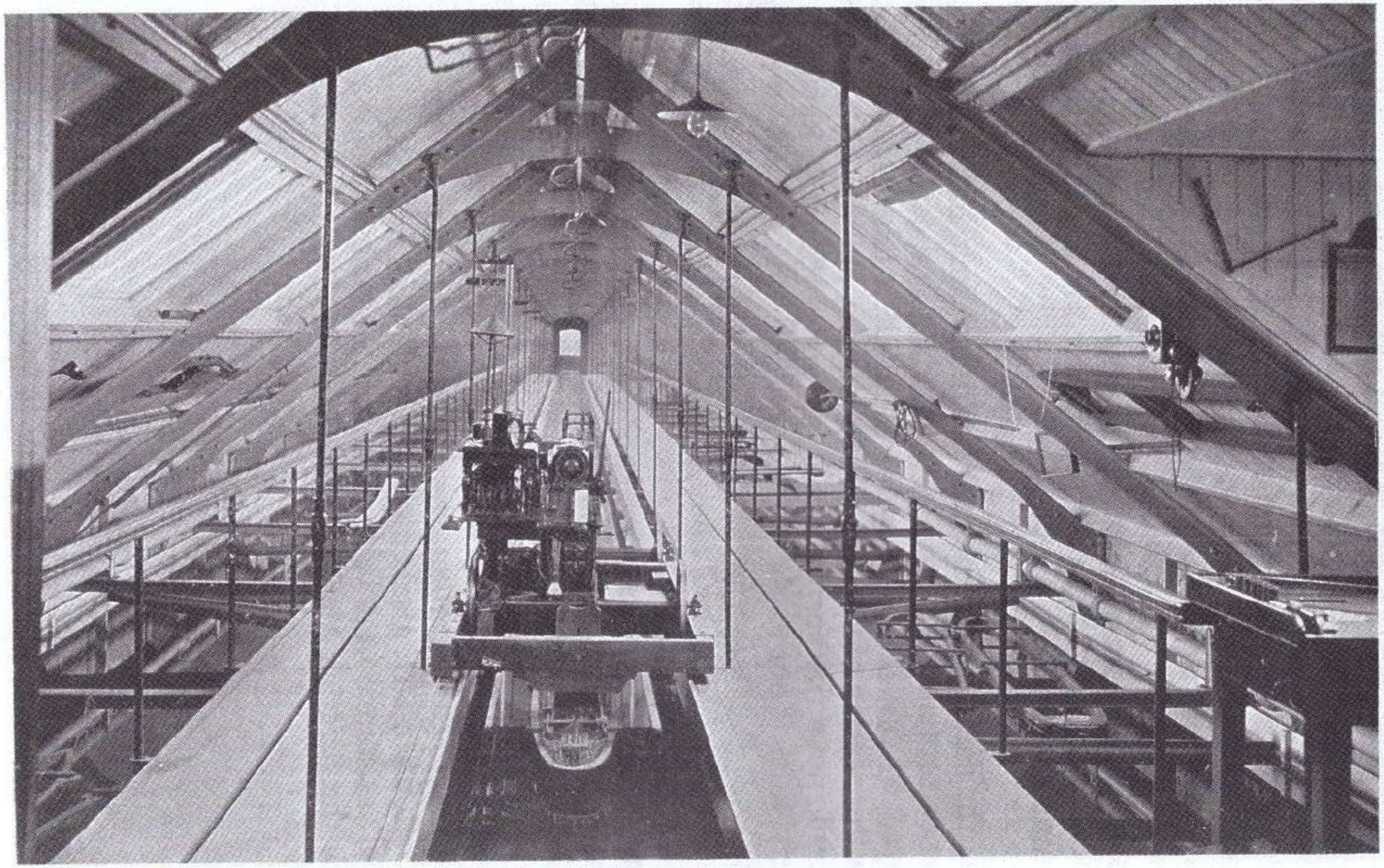
About 1839 two Scottish shipbuilders built experimental test tanks. Alexander Hall & Co of Aberdeen had a small 3M long glass test tank before building the schooner SCOTTISH MAID, and the 4th Duke of Portland, William Henry Bentinck, had one complete with overhead railway at his Troon shipyard to test a model of the steam yacht FIRE KING. In 1870, William Froude (1811-1879), successfully fitted bilge keels to the GREAT EASTERN to reduce her rolling. With Admiralty patronage, Froude started building his model tank at Chelston Cross, near Torquay, in 1871. The first experiments taking place on 3rd March, 1872. By 1875 he had established a formulae to determine the resistance of a vessel from the results of a model of the vessel. This encouraged William Denny (III) [1847-1887], to send to Froude the lines and progressive trial results of the single screw steamer MERKARA for tank testing. The results compared so well that Denny was convinced that tank testing was the way forward. The Torquay tank was about 85 metres long, 11 metres wide, 3 metres deep and of triangular cross section. The tank contained about 2,500 tonnes of fresh water and was suitable for models up to 5 meters in length. From 1873 to 1878, Mr Frank P. Purvis (1850-1940) worked at the tank, as did Mr Edwin R. Mumford (1859-1926) from 1878 to 1882.

THE DENNY PARTNERS TAKE THE PLUNGE

In 1881 William Denny persuaded the other partners of the firm that it would be commercially advantageous to have their own tank. The architect engaged was the Greenock born John Crawford, who went on to design the tanks at Clydebank and Nagasaki. The recording truck or carriage for towing the models was designed and supplied by Wm. Kelso & Co., electricians and model makers, Glasgow. Kelso supplied and fitted the equipment for test tanks all over the world. In 1884 John McDowall & Sons, Johnstone, supplied the wax model cutting machine, based on Froude's design, at a cost of £600. This company also invented the Eccentric Turning Lathe, the Screw Pump and a bottle cork cutting machine.

The completed tank and apparatus costing about £6,000. The tank was originally 73 metres long, 6.7 metres wide and 2.75 metres deep having a uniform rectangular cross section with an additional 18 metre long dock, at the north end, and a 16.5 metre one at the south end. Purvis was the tank's first superintendent, leaving in 1889. In 1902 he took up the chair of naval architecture at Tokyo University. Mumford came to Dumbarton in 1882 and together they ran the first model test on 21st February, 1883. In honour of William Froude, Denny dedicated the facade of the building to his memory. William Denny defined the function of the tank as "To determine with commercially acceptable accuracy the power required to achieve the contract speed, and to reduce that power for any installation to a minimum."

In 1924 the south end of the tank buildings, including the cell room and generators and the propeller moulding and casting room, was destroyed by fire. The opportunity was then taken to extend the deep water section of the tank by 16.5 metres, making it 94.5 metres long, and move the suspension links, supporting the Burma teak gangway, further out to give a clear walkway on each side of the rail track. Tank Superintendents over the years have included Edgecombe, P Fleming, James Allan, William Walker and Hans Volpich. The tank staff of about 17 comprised experimenters, girl analysts and tracers, model makers and mechanics. The tank was purchased by Vickers-Armstrongs (Shipbuilders) Ltd., in May 1964, with David Moor as superintendent, followed by Tom Glen and finally GA Campbell. In 1975 a wind tunnel was added to the tank's facilities. In July 1977, the tank passed into the hands of British Shipbuilders Ltd. In 1983 the National Maritime Museum in Greenwich instigated a scheme to save the tank for posterity. With financial assistance from various bodies, the tank was purchased in 1984 by the Scottish Maritime Museum for £50,000 and suitably converted for public access.



THE TANK IN 1908

THE CARRIAGE OR TRUCK

The narrow gauge railway (40" or 1016mm) is suspended from the roof about 0.5 metre above the water level and is cambered to suit the earth's curvature. Originally the truck was towed by an endless wire rope worked by two stationary single cylinder 4 horse power (3 kW) Tangye steam engines coupled together. In 1908 steam gave way to electricity in the form of a 130 cell battery powering an 8 HP (6 kW) motor driving the two wheel axles which were now fitted with automatic solenoid brakes. Although the carriage could reach 366 metres per minute (13.6 MPH) the maximum continuous speed was 305 metres/min. Over the years the carriage has been upgraded, the present one being the seventh. In 1939 a weight catapult was fitted to provide rapid acceleration over the first 15 metres to give 22.7 MPH. The equipment on the carriage records the power, speed, sinkage and trim of the model. A separate Froude type screw propeller dynamometer and carriage measured the thrust and torque of a single propeller in open water and behind the hull. In 1909 this was altered so that up to four propellers could be utilised simultaneously, patented in 1912. Mumford later drove the model via its own propeller until the dynamometer zeroed, thus proving the system. In 1955, the electrical mains supply was changed from DC to AC power. Finally a computer was mounted on the carriage and programmed to drive the model at the required speeds and record all the data.

THE WAVE MAKER

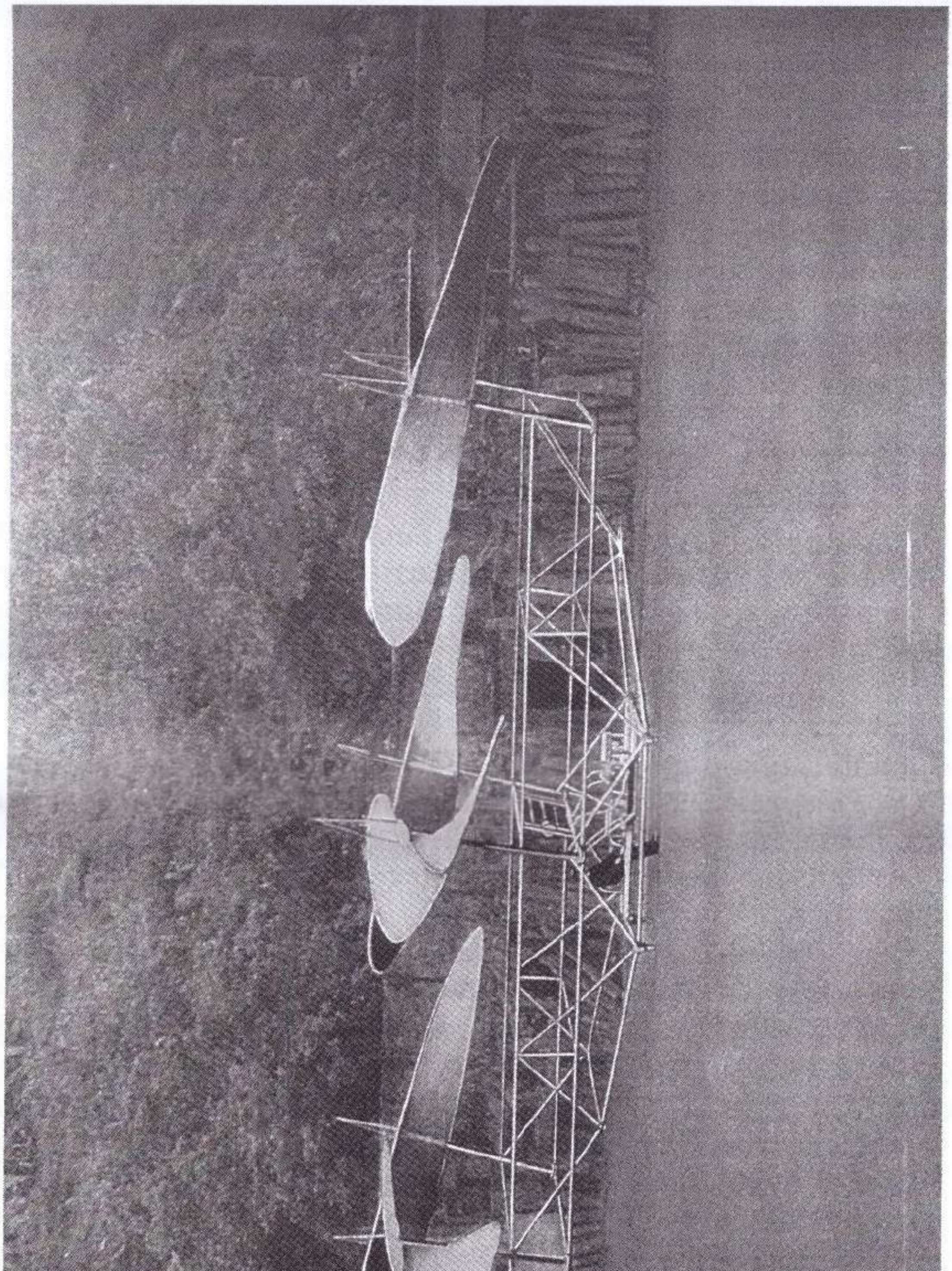
In 1887 the tank installed its first wave maker. It consisted of a broad wooden board stretching the full width of the tank and was hinged at its lower end. Man-power was the energy source and the movement was timed by the beat on a drum, something akin to the Roman Slave Galleys. By 1935 a series of power driven wave makers of the vertical plunger type had been fitted. A more sophisticated wave maker was later installed by the University bodies in 1996.

PADDLE WHEELS, VANE WHEELS AND PROPELLERS

In the early days of the tank (circa 1886) much attention was given to paddle wheels and many self-propelled models fitted with radial, fixed and feathering paddles were tested. The importance of float area, immersion, and location to the wave profile were all examined. A result of this work was the placing of an order with Wm Denny by the Belgian Government, in 1887, for two 20.5 knot paddle steamers, PRINCESS HENRIETTE and PRINCESS JOSEPHINE. A total of 14 models and 7 pairs of paddle wheels were investigated before the final dimensions, form and paddle wheels were fixed. On completion, these two vessels were the fastest in the world, apart from torpedo boats. Robertson Buchanan of Glasgow is credited with having patented the first feathering paddle wheel in 1813. Two examples of model feathering paddle wheels are to be seen; one of 0.5 metre in diameter over the 9 floats which has been used in the tank since about 1920, and a similar one of 1.0 metre diameter having curved floats, built in 1944 and designed by Mr Barback. This larger wheel was restored to its original condition in 1990 by 5 apprentices from the Clyde Submarine Base. Both wheels were used to establish a systematic series for paddle wheels, which was published in 1957 by Mumford and Allan. In the 1920's three different vessels were built having vane wheels at the stern as their means of propulsion, the model wheels are on display. Also on display are some of the model propellers designed and made at the tank of either Magnolia Metal or Fry's metal. It took a skilled technician a week to cast, fair and balance a propeller. Over 600 model propellers were made, mostly of the three bladed variety ranging from 64 to 275mm diameter, and are on display.

THE STANDARD MODEL

All model test tanks have a standard model which is run periodically, to ensure that the results are constant. The Denny Tank has a double ended brass one, made in 1930, which can be seen at the entrance to the tank. In the drawing office, upstairs, can be seen the resistance curve for this model.



MUMFORD HELICOPTER January 1913

TANK TESTING THE MODEL

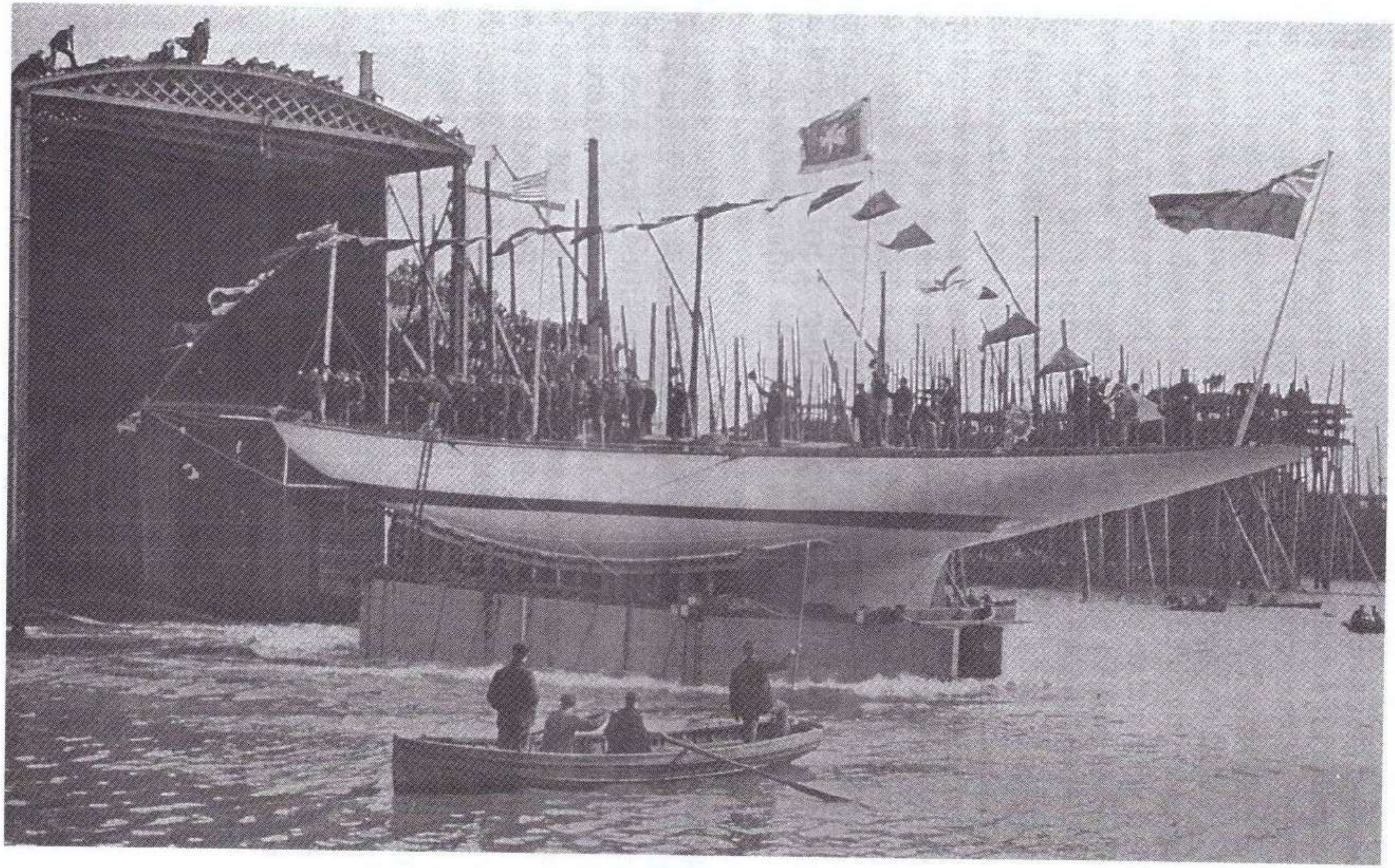
The model resistance was firstly determined by running it naked, i.e. without appendages, over a range of speeds, and then run again with appendages, and finally the propeller/s fitted and a set of self-propulsion tests carried out over the same speed range. If required, sea-keeping tests in waves were carried out with the model restrained. Larger radio controlled models, up to 15 metres in length, were tested in the Gareloch.

THE MUMFORD HELICOPTER

In 1900 Edward Mumford, the Tank Superintendent, collaborated with a Spaniard named Vergara and carried out experiments at the tank on a form of orthinopter. After Mumford patented his design in 1905, under the utmost secrecy, he carried out experiments with air screws, initially utilising the joiner's shop which had a greater height. Later a full size machine without an engine was tested in a shed in the hills above Overtoun. The shed and machine were destroyed in a gale. A second machine was built in 1906, designated SO 60, having six two bladed propellers, of 7.6 metre diameter, on vertical shafts inclined at 10 degrees, all geared to one French petrol driven engine delivering 25 HP at 1100 rpm. The bamboo framed propellers were chain driven through a 3:1 reduction gearbox. The machine was too heavy and the engine too small. The machine was rebuilt in 1909 and finally with a new engine of 25 HP, aluminium framework, and piloted by J. Pollock Brown, the tethered machine lifted off the ground 3 metres at the foot of Dumbarton Rock in September, 1912, and again in January, 1913. Late in 1914, the final 40 HP version with floats, weighing about 685 kg, was said to have been successfully tested on the river, only to be later destroyed in a gale.

THE MOULDING AND SHAPING ROOM

This room is equipped with two cast-iron boxes in which models up to 6 x 0.9 x 0.6 metres can be moulded to their appropriate shape in clay, and cast in specially refined paraffin wax containing 0.5% bees wax. 48 hours prior to being required, the wax is heated to 82 Degrees C using steam heating coils, then purified and strained from the top melting box into the ones below, the steam being supplied from the boiler beneath. The clay bed shape is determined using the standard 13 station wooden half section boards together with bow and stern templates. The lath core is covered with calico and smeared with soft clay before being clamped into place on the casting box. As the wax is poured into the gap between clay and core, water is added to the core to maintain positive pressure. The wax is allowed to set overnight before removing the core the following morning. The model, which can weigh up to 360 kg, is then fitted with 3 standard locating beams before being floated out of the clay bed and on to the cutting machine. The lines plans were drawn on linen backed cartridge paper mounted on standard 2.15 metre wooden boards. The machine scales up the model lines by choosing one of a series of geared tooth wheels, as required. Sitting on the automatic elevating stool, the operator traces the waterlines from midships to bow and stern. The cutters are at a fixed height and the carriage table is raised for each subsequent waterline. Before removing the model from the cutting machine the standard 13 stations [0, ½, 1, 2, 3, 4, 5, 6, 7, 8, 9, 9½ & 10] are marked on the model for reference. Station 0 being the after perpendicular, station 5 being midships and station 10 is the forward perpendicular. It is then transferred up to the finishing room for fairing, checking and polishing. Any appendages e.g. bilge keels, rudders, underwater fenders etc are later fitted here also. The model is then transported down to the tank dock area where it is weighed in order to assess the amount of ballast that has to be added to arrive at the correct displacement. The model is then floated in the dock and the calculated ballast added to bring the model to the required waterline and trim. The "J" type waterline pins are then utilised at the bow and stern to check that the model is floating correctly at the required draught before being connected to the truck or carriage.



SHAMROCK II LAUNCH 20th April, 1901

THE DRAWING OFFICE

This room contains various records; a drawing board with weights, instruments and calculators, such as Fuller's barrel slide rule; Amsler's planimeter and integrator; a typical model lines plan and two scale models of the Cutty Sark b1869 and PS Thooreah b1880. This set of offices were constructed in 1903 and extended towards the exhibition room in 1959.

THE DENNY-BROWN FIN STABILISER

A Stirling chemist, Mr Wilson, patented his fin stabilisers in 1898. Dr Shintaro Motora, Mitsubishi, first invented gyroscopic controlled ship-stabiliser fins in 1920, and successfully fitted them to three Japanese vessels by 1932. In 1931 William Wallace (1881-1963) of Brown Bros., steering gear manufacturers, Edinburgh, proposed that they collaborate with Denny to develop a stabiliser. In December 1933, the two firms took out a licence for the sole UK manufacturing rights for the Motora stabiliser. The electrical interface was supplied by Muirhead & Co. and the first fixed installation was fitted onboard the passenger ferry ISLE OF SARK in 1938. The Admiralty then caused all commercial exploitation of the system to cease when they fitted fins to HMS BITTERN using three gyroscopes, based on their experience with gun control systems. By 1950 over 100 warships had been fitted with Denny-Brown fins at which time the Royal Commission to Awards to Inventors awarded £27,500 to the two companies and £300 to Mr J. Bell, an MOD electrical engineer. Improvements to the fin followed, first by drawing it inboard into a tubular recess and later by hinging it inboard, utilising the invention of a Russian engineer.

TRIAL RESULTS

About 1875 William Denny (III) was the first to introduce progressive speed trials over the measured mile, a system that is still practised today. The trial results of all the Denny vessels which were tank tested are held at the tank today. Up until about 1939 homing pigeons were used for transferring the trial results from the ship to the tank for analysis. The doocot was in the main office block of the adjoining shipyard above the print room.

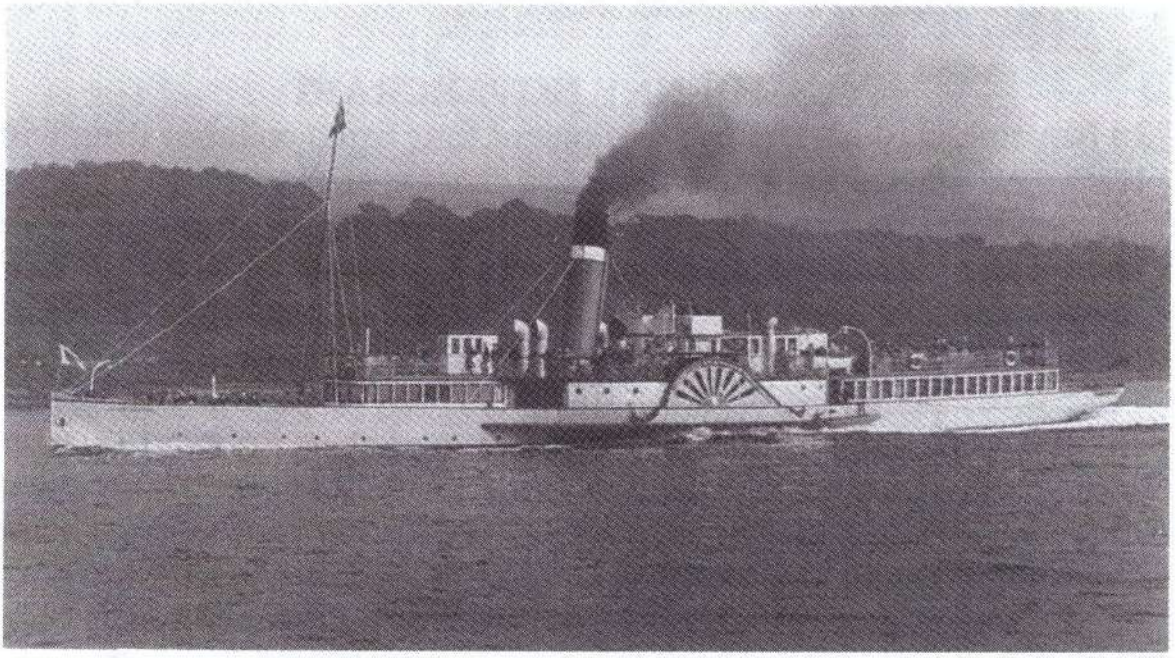
A WIDE SPECTRUM OF EXPERIMENTS

Over the years the tank has seen many experiments, not just with sea-going ships, but submarines, anti-mine paravane cutters (invented 1916 by Lieut. Charles Dennistoun Burney), Thomas Lipton's yachts SHAMROCK II and III, flotillas of barges for towing in African rivers (the tank being drained down to 150mm of water), the 13 metre 52 knot hydrofoil MTB 109 for the Admiralty in 1942 and finally the Denny Hovercraft in 1961. In 1896 shallow water effect was investigated by laying a temporary wooden bottom in the tank. Later a portable one of 43 metres long x 3 metres wide was arranged. The tank also carried out model testing for other shipbuilders. In 1960 they assisted Harland & Wolff by proposing open propeller shafts and designing a bulbous bow for the CANBERRA in order that she could attain her contract speed. Various models of bulbous bows are on display in the tank.

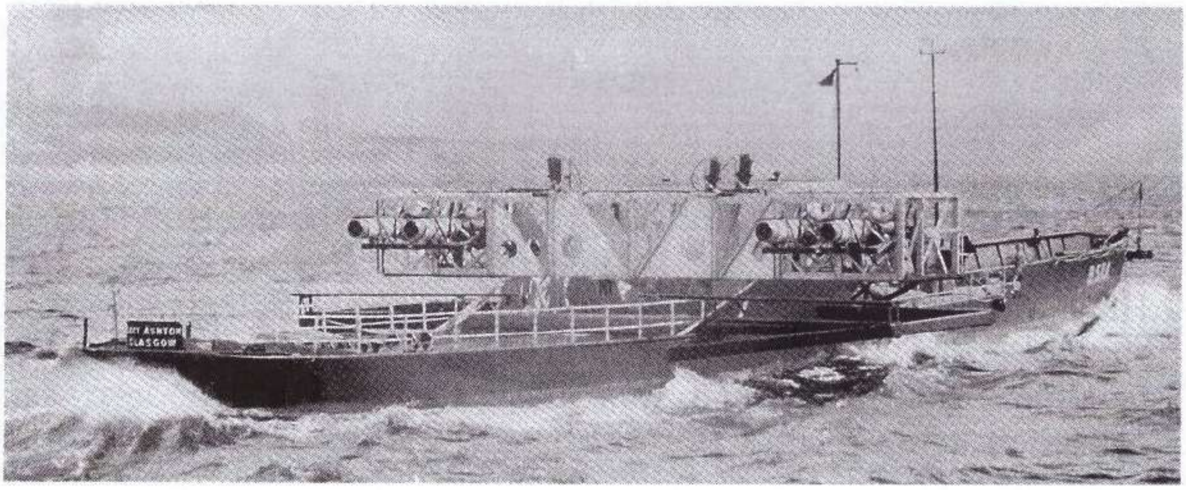
THE LUCY ASHTON EXPERIMENTS

In 1950, under the auspices of the British Ship Research Association, the old Clyde paddle steamer LUCY ASHTON was used to examine Froude's law of comparison for frictional resistance, by comparing it with models of the vessel, made by 6 other tanks. Stripped down and fitted with 4 jet engines having a total thrust of 7.2 Tonnes, she was run at 12 knots over the measured mile in the Gareloch. 58 days after running the vessel with a clean hull, she was run again to establish the addition due to fouling. An increase of 50% was found. Finally in 1957 at an annual International Towing Tank Conference in Madrid, an ITTC friction line was agreed.

PS LUCY ASHTON



As a Clyde paddle steamer (1888 to 1948)



When stripped down and fitted with jet engines 1950

THE DENNY HOVERCRAFT

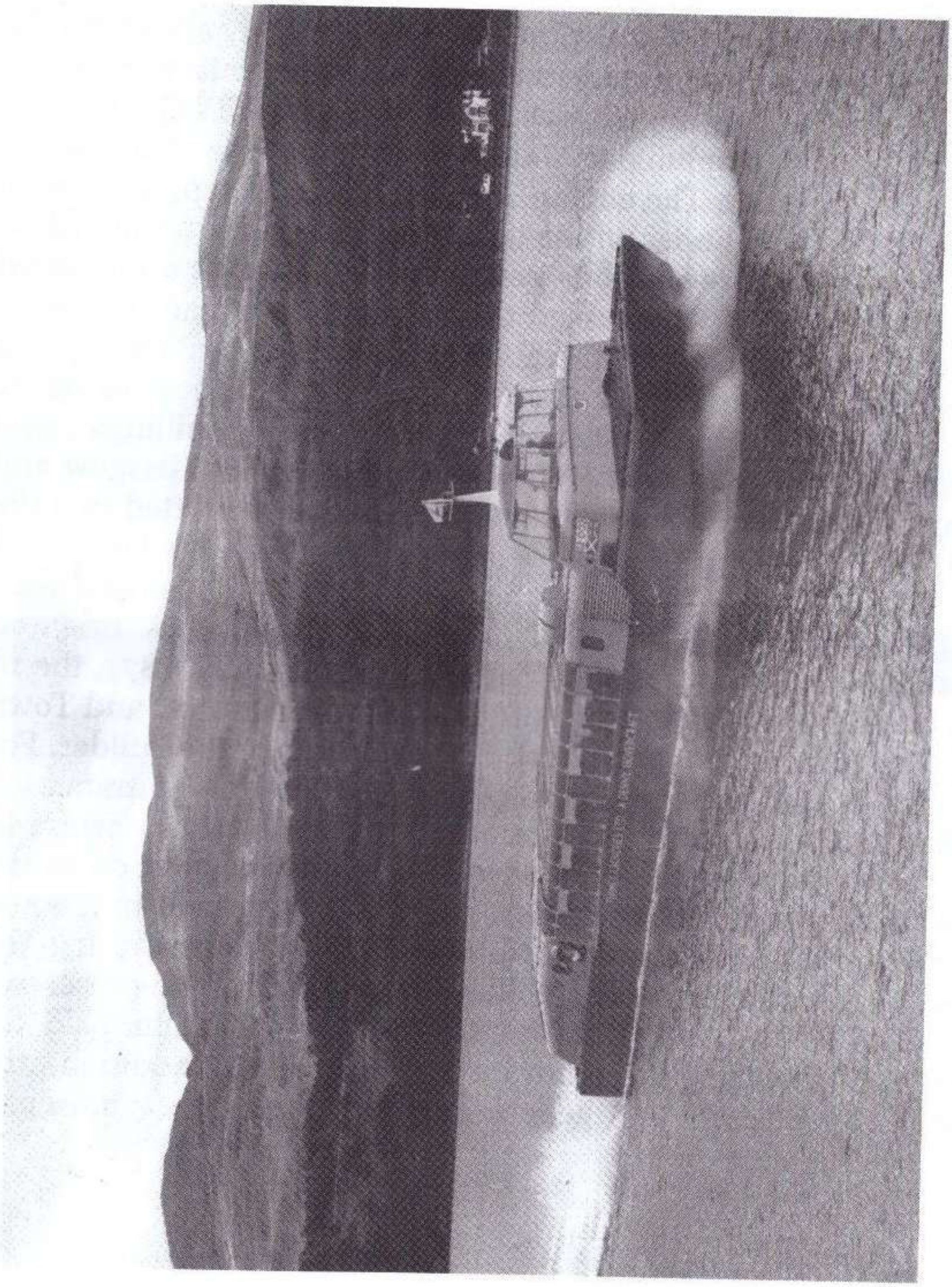
In November 1960, Denny were one of four firms collaborating with Hovercraft Development Ltd on the design of Hovercraft. The 5.5 Tn prototype D1, built of plywood and sheet metal, comprised twin fixed wall skirts enclosing an air cushion serviced by 2-25 HP fans. Propulsion was by means of two 35 HP Mercury outboards which propelled the 18 metre craft at 22 knots in the Gareloch on June 22^{nd}, 1961. Denny set up a separate company to promote the 28 Tn D2-002 GRP version to carry 70 passengers at 25 knots utilising 2-150HP diesel driven fans and 2-220HP Schottel propulsion units. The vessel made the 800 mile voyage to London via the Crinan and Caledonian canals but failed to attract the necessary interest as the fixed skirts scooped up the river debris causing damage to skirt and propellers when it was demonstrated on the Thames in July, 1963. The D2 remained idle until 1968 when it was run commercially between Barrow and Fleetwood. Finally a D3 version was planned at 46 x 15m and weighing 135 Tn, designed to carry 600 passengers at 40 knots.

THE DENNY TANK TODAY

In 1988 the Department of Naval Architecture of the University of Strathclyde first used the Denny Tank to carryout experiments. Having access to such a unique facility proved extremely useful for student projects. The true potential of the test basin was recognised in 1996 when a decision was made to invest in modern data collection equipment, a state of the art motion capture system, a new controllable wave maker and an absorbing beach. This modernisation opened the door for a number of research and commercial testing projects as well as Undergraduate and Post Graduate student projects. Due to financial restraints the university withdrew from the Denny Tank in 2006 and removed their equipment.

THE NAPIER STEAM ENGINE

Standing in the grounds, which was formerly the garden of Denny's yard manager's house, is the first marine steam engine built by Robert Napier (1791-1876) of Dumbarton in 1824. His works were at Camlachie, near Govan, Glasgow. The engine was designed by the work's manager, David Elder (1785-1866). There was no precedent for this wrought iron construction, which was mainly accomplished by cartwrights and house joiners using very rudimentary machines and cold chisels. This engine was fitted in the PS LEVEN, built by the Dumbarton shipbuilder James Lang for the Dumbarton Steamboat Company. The engine is of the side lever type and has a 762mm diameter cylinder with a 915mm stroke which produced 30 Horse Power at 48 revolutions per minute. The engine was fitted with an eccentric which enabled the vessel to go ahead or astern. The vessel sailed between Dumbarton and Glasgow. During the summer she took the "Sons and Daughters of the Rock" as far as Ailsa Craig for 7 shillings (35p) First Class, and 5 shillings (25p) Second Class. In 1841 the LEVEN was broken up at Glasgow and the engine removed. Four years later the engine was fitted into the PS QUEEN OF BEAUTY, built by Robert Napier at his Lancefield works. The engine drove two paddle wheels of 3.65m diameter each with 14 floats. The vessel plied from Liverpool to New Brighton until 1863 when she was broken up at Govan. In July, 1877, the 10 tonne engine was presented to the Provost, Magistrates, and Town Council of Dumbarton, by JR and J Napier, sons of the builder. For 92 years it sat on its stone plinth outside the entrance to Dumbarton Castle until it was removed to the new town centre in 1969. In 1985 the engine was moved to its present position in the Denny Tank grounds. During this operation the plinth broke and the District council then spent about £3,000 in renovating the engine. The engine is the third oldest in the world to be preserved. In July of 2005, West Dumbartonshire Council again paid for Heritage Engineering to renovate the engine. In addition, the Council continues to generously support the museum.



DENNY HOVERCRAFT D2 002

MODEL TESTING AND ITS APPLICATION TO SHIP RESISTANCE & POWERING

Having previously briefly described how the model is tested, it is necessary to explain, hopefully in the simplest possible terms for the layman, how the recorded speed and resistance of a model is converted into the speed and power for a ship. It is here that William Froude's laws are indispensable. Froude considered that the total resistance (Rt) of a model or ship could be subdivided into two parts with little interaction, and each part being subject to different scaling laws, ie resistance due to skin friction (Rf) and resistance due to wave making known as residual resistance (Rr), such that: Rt = Rf + Rr.

By towing a series of thin planks of various lengths, Froude arrived at an empirical formula for frictional resistance, such that: $Rf = f A V^{1.825}$

where f = a constant dependent on the length of the model or ship, varying from

0.057 for a 3m long model to 0.042 for a 300m long ship

A = the wetted surface area of the model (wsa) or ship (WSA) in m^2.

V = the speed in knots of the model or ship

The residual resistance (Rr) is the difference between the total resistance (Rt) and the frictional resistance (Rf), ie Rr = Rt – Rf. The tank measures Rt. Froude went on to discover that for two vessels of similar form, ie a ship and her model, the corresponding speeds are proportional to one another as the square roots of their lengths; and at these corresponding speeds, the resistance of the two vessels are proportional to one another as the cubes of the similar dimensions. Let l, v and r = the length, speed and resistance of the model; and L, V and R = the length, speed and resistance of the ship. Suppose we use Denny's last ship MELBROOK as an example, which had an 7,162 BkW main engine. This vessel had a waterline length of 150m, a breadth of 20m, a draught of 9.15m and a speed of 15.5 knots was required. If the model is $1/25^{th}$ scale at 6m long then the required speed of the model (to represent the ship at 15.5 knots) is:

$v = V\sqrt{l/L} = 15.5\sqrt{6/150} = 3.1$ knots (3.57 mph)

Let us assume that the total resistance of the model at this speed of 3.1 knots is 4.36 kilograms and the calculated skin friction resistance of the model (7.0m^2 wsa) using an 'f' value of 0.05 is 2.74 kilograms, giving a residual resistance of 1.62 kilograms. This residual resistance is then scaled up for the ship using Froude's law of similarity : $Rrs = Rrm\,(L^2 \times V^2)/(l^2 \times v^2)$

where Rrs is the resistance of the ship and Rrm is the resistance of the model:

Thus $Rrs = 1.62(150^2 \times 15.5^2)/(6^2 \times 3.1^2) = 25{,}371$ kg

The skin friction resistance for the ship at 15.5 knots can now be calculated using an 'f' value of 0.043 and WSA of 4700m^2; ie 30,056 kg. Thus the total resistance (Rt) for the ship in salt water is: $1.025(25371 + 30056) = 56{,}813$ kg

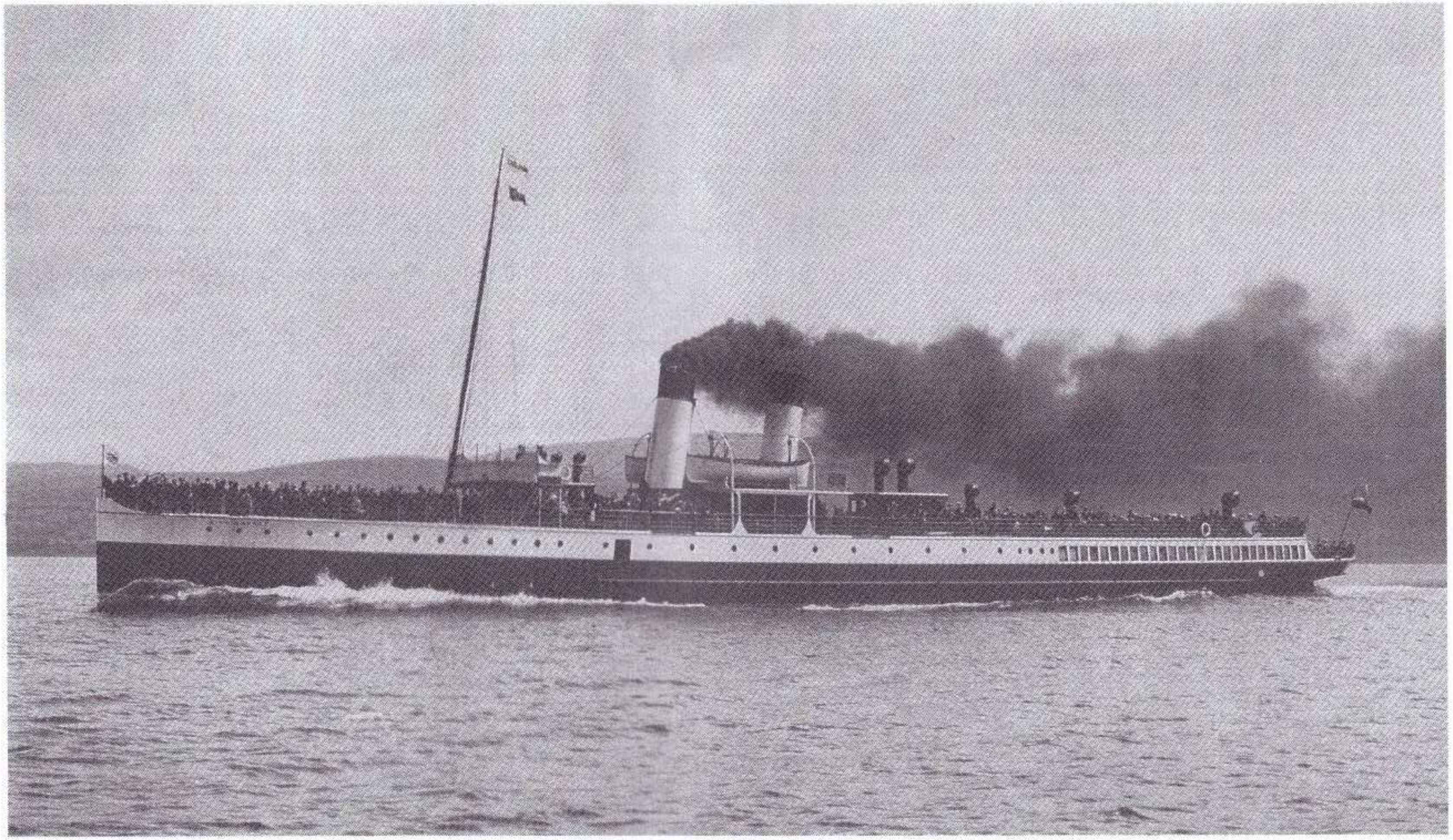
The unit of power is a "kilowatt" (kW), which is taken as 6,118 metre-kilograms of work performed in one minute, and the UK nautical mile is 1853 metres. The resistance is then converted into effective power for the ship at 15.5 knots:

Effective Power = $(15.5 \times 56813 \times 1853) / (60 \times 6118) = 4445$ EkW

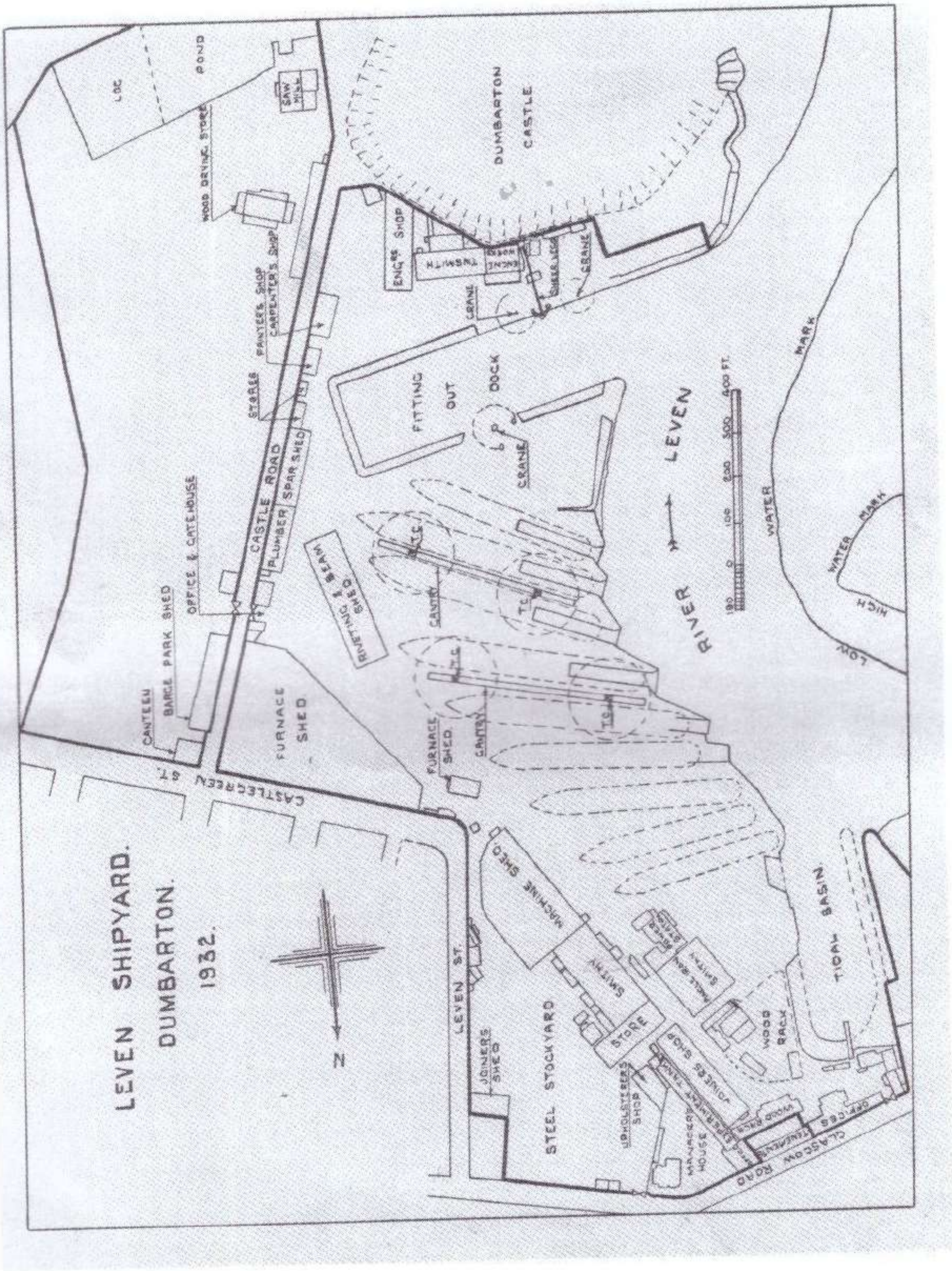
Allowances for appendages eg bilge keels etc, fouling and air resistance are then added to this value (approximately 6%) would result in a total effective power of 4,712 EkW being required at the propeller. In addition, allowances for the efficiency of the hull, propeller, shafting, gearbox etc are then taken into account, which can vary from 40% to 75%. Assuming our ship's transmission and propeller system is 67% efficient, and the propeller (at 115 rpm) for this single screw ship is designed to absorb 90% of the installed power, the ship would require an engine power of: $(4712 \times 100^2) / (67 \times 90) = 7{,}162$ BkW

J Craig Osborne

25th January, 2007



TRS KING EDWARD
The first turbine powered merchant ship in the world
Built in 1901 at a cost of £24,773


LEVEN SHIPYARD.
DUMBARTON.
1932.
N
DUMBARTON CASTLE
FITTING OUT DOCK
CRANE
RIVER LEVEN
WATER MARK
LOW WATER MARK
HIGH
CASTLE ROAD
CASTLEGREEN ST.
LEVEN ST.
GLASGOW ROAD
TIDAL BASIN
FURNACE SHED
MACHINE SHED
STEEL STOCKYARD
JOINERS SHED
SMITHY
STORE
WOOD RACK
OFFICES
MANAGERS HOUSE
UPHOLSTERERS SHOP
JOINERS SHOP
RIVETING & BEAM SHED
GANTRY
PLUMBER
SPAR SHED
STORES
PAINTERS SHOP
CARPENTERS SHOP
ENGRS SHOP
WOOD DRYING STORE
SAW MILL
POND
OFFICE & GATEHOUSE
BARGE PARK SHED
CANTEEN
FURNACE SHED
0 100 200 300 400 FT.