Use of a Water Channel for Model Tests on Planing Hulls

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A comparison has been made of the resistance characteristics of two of the DTMB series 62 planing hulls obtained from measurements made in a high-speed recirculating water channel and a towing tank. The results showed good agreement at the DTMB standard displacement ratio, provided a correction was applied for shallow water effects due to the restricted working section depth. The results suggest that, with the present size models, resistance measurements can be made for a displacement ratio ($A_P/\nabla^{2/3}$) not less than 7.0. Further work is envisaged on the use of smaller models, in order to extend the range of displacement ratios that may be investigated.

Nomenclature

A_P = projected planing bottom area, excluding spray strips
B_P = beam over chines, excluding spray strips
B_{PA} = mean breadth over chines, A_P/L_P
B_{PT} = breadth over chines at transom, excluding spray strips
B_{PX} = maximum breadth over chines, excluding spray strips
F_∇ = Froude number based on volume displacement, $V/\sqrt{g\nabla^{1/3}}$
L_P = projected chine length
LCG = longitudinal center of gravity
R = total resistance
R_{Rd} = shallow water residual resistance
$R_{R\infty}$ = deep water residual resistance
V = water speed
W = displacement at rest (weight)
d = depth of water
h = vertical displacement of center of gravity
α = change in trim angle from at rest condition
β = deadrise angle
∇ = displacement at rest (volume)

Introduction

THE complicated nature of ship resistance has meant that considerable use has been made of model experiments to investigate basic hydrodynamic phenomena and to predict the performance of the full-size vessel. The most common technique used to determine the hydrodynamic forces on a model is to tow it through a tank of stationary water. This method is believed to date back as far as Leonardo da Vinci, although a more usual historical base line is the work of W. Froude, who established the first towing tank in 1872. An alternative technique is the converse idea of holding the model still in a controlled current of water. This method, analogous to the wind tunnel used by aerodynamicists, offers many apparent attractions, such as very long running times, easy flow observation, and stationary instrumentation, but the development of a successful water channel or flume has proved to be difficult. This is particularly so if any attempt is made to measure hydrodynamic forces as opposed to merely making observations of flow patterns. The results presented in this paper are of measurements made on two planing hulls using a high-speed recirculating water channel, which has been developed so that the flow in the working section is uniform with a flat and horizontal free surface. The purpose of the investigation was to compare the results obtained in the water channel with published towing tank data, in order to determine any limitations on the range of model displacements that might need to be imposed due to the restricted size of the channel's working section.

Recirculating Water Channel

The model tests were carried out in the recirculating water channel (or flume) at the University of Liverpool. The channel, which is shown in Fig. 1, has a working section 1.4 m wide, 0.84 m deep, and 4.0 m long (4.5×2.75×13 ft) and a capacity of 90,000 liters (20,000 gal) circulated by an impeller driven by a 135 kW motor. From the impeller, the water passes through a long conical diffuser, after which the section becomes rectangular. The water flow passes through two sets of guide vanes and a honeycomb to minimize swirl and is then accelerated through the closed contraction into the working section. The top layer of water, which contains most of the larger entrained air bubbles, is separated at the downstream end of the working section by a splitter plate or adjustable flap. This water is slowed by a deepening of the local section, passing through several gauzes to allow time for the air to escape before it is reintroduced to the main circuit upstream of the impeller. A further advantage of the splitter plate is that, since the flow over the plate is supercritical at almost all speeds, wave disturbances are not transmitted upstream into the working section.

The flow velocity in the working section can be set within a range 0.03-6.1 m/s (0.1-20 fps). Due to the adjustable floor, any speed can be maintained without the presence of standing waves or a hydraulic jump – the critical speed with the floor in its lowest position would be in the region of 2.7 m/s (9 fps).

Early work in the flume[1] showed that there was an appreciable wake at the free surface caused by the boundary layer on the upper surface of the contraction. In order to correct this, a jet injection system was installed – water is bled off from the lowest part of the return circuit and pumped through a 1-mm wide slot running the full width of the channel at the upstream end of the working section. By adjusting the pump speed, the velocity defect at the free surface can be corrected with the beneficial side effect of further improving the flatness of the free surface.

A detailed account of the design of the channel has been given by Preston.[2]

Experimental Facilities and Method

The DTMB series 62 hulls were used and models were made in glass reinforced plastic (grp), one-half the size of the original DTMB models of the revised parent hull (model 4667-1) and model 4666. These were taken to represent hulls which would be appropriate to fast patrol boats and motor yachts,

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Received July 2, 1976; revision received Oct. 6, 1977.
Index categories: Research Facilities and Instrumentation; Marine Hydrodynamics, Vessel and Control Surface.
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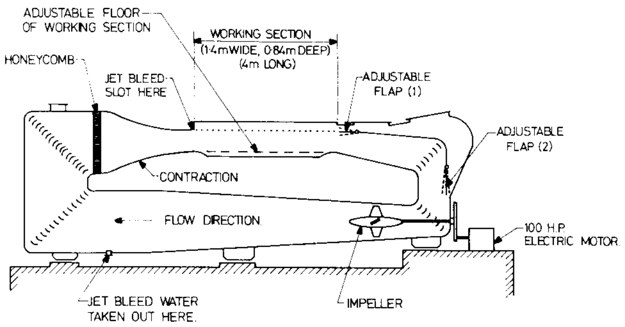

Fig. 1 Diagram of high-speed water channel.

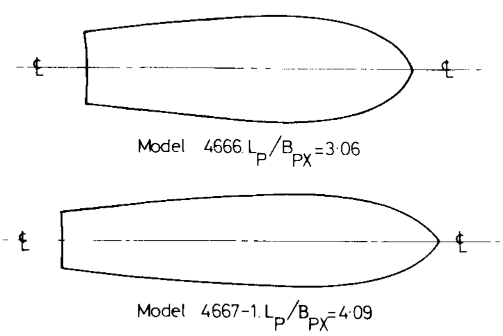

Fig. 3 Chine lines in plan view of the two models of the DTMB series 62 hulls.

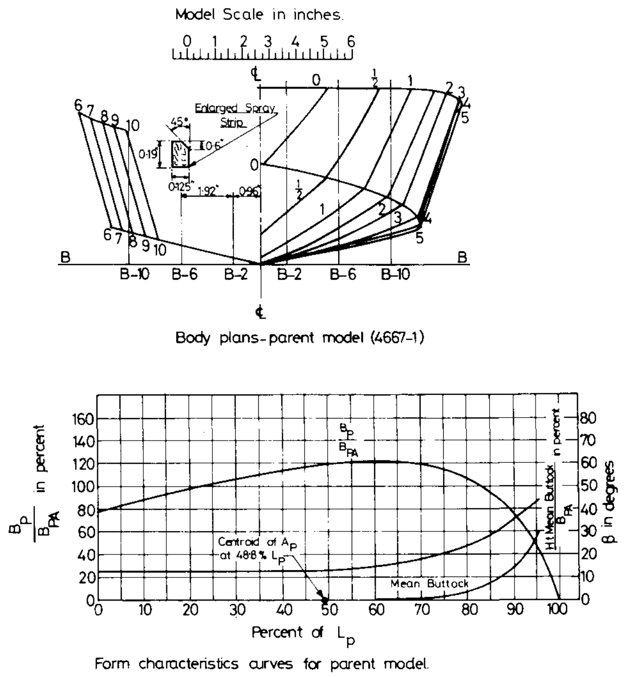

Fig. 2 Body plan and form characteristics curve for DTMB series 62 revised parent model (4667-1).

respectively. The body plans of the two models are given in Figs. 2 and 3, and other data are given in Table 1 and Ref. 3.

The model was floated in the channel attached to a balance through a tow point on the shaft line, as in Ref. 3, which allowed the hull to trim and heave while measuring resistance and vertical displacement. An indicator mounted at the bow recorded trim, while also providing an additional restraint against large yawing forces which might occur with forward center of gravity positions. Scales along the keel, chine, and transom of the model enabled the respective wetted lengths to be determined. Other work[4] has shown that for planing surfaces in the channel there is no measurable change in the resistance due to channel width, provided the beam is less than 300 mm and also that no form of turbulence stimulation is necessary at speeds above 1.2 m/s (4 fps).

Measurements were made of resistance, heave, bow height, and wetted area over a range of speeds on both models at the DTMB standard condition, i.e., with the center of gravity 6% aft of the centroid of the planing area and at a displacement ratio of 7.0. Subsequently, similar measurements were made on the beamier hull (model 4666) at two heavier displacements and at four positions of the center of gravity.

Presentation of Results

For a given hull size and design, the variables which affect the planing characteristics of the hull are the displacement (W or ∇), the longitudinal position of the center of gravity (LCG), and the speed; these were defined using the parameters given by Clement and Blount.[3] The displacement is expressed as the dimensionless ratio $A_P/\nabla^{2/3}$, where A_P is the projected planing bottom area and ∇ the volume of water displaced at rest. It should be noted that with this ratio a high numerical value implies a light displacement condition and a low value correspondingly a heavy displacement. The longitudinal position of the center of gravity was defined as the LCG position aft of the centroid of A_P expressed as a percentage of the projected chine length. The speed was given in terms of a Froude number F_∇, based on the cube root of the displacement as the representative length.

The results have been expressed in terms of the resistance as a ratio of the weight (R/W), the change in trim angle (α), and the change in vertical height of the center of gravity (h) against the Froude number F_∇.

Table 1 Model dimensions

	Model 4666		Model 4667-1	
A_P	2.429 ft^2	0.2256 m^2	3.200 ft^2	0.2973 m^2
L_P	2.994 ft	0.9124 m	4.000 ft	1.2192 m
B_{PA}	0.812 ft	0.2475 m	0.800 ft	0.2438 m
B_{PX}	0.978 ft	0.2981 m	0.978 ft	0.298 m
B_{PT}	0.693 ft	0.2112 m	0.625 ft	0.1905 m
L_P/B_{PA}	3.69		5.00	
L_P/B_{PX}	3.06		4.09	
B_{PX}/B_{PA}	1.21		1.22	
B_{PT}/B_{PX}	0.71		0.64	
Centroid of A_P, $\%L_P$ forward of transom	48.2		48.8	
Angle of chine in plan view, deg	5.0		5.0	
Half-angle of waterline entrance, deg	49		46	

The results obtained in the towing tank were taken from Ref. 3 and have been scaled to the model size of the present tests using the A.T.T.C. friction correlation line (Ref. 5) with zero roughness allowance.

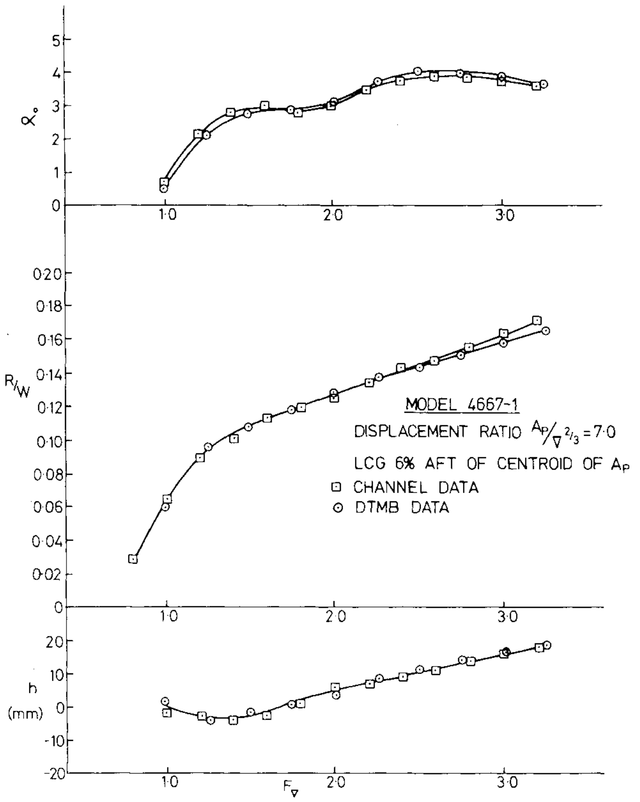

Fig. 4 Comparison of results obtained in the water channel and towing tank – model 4667-1, DTMB standard condition.

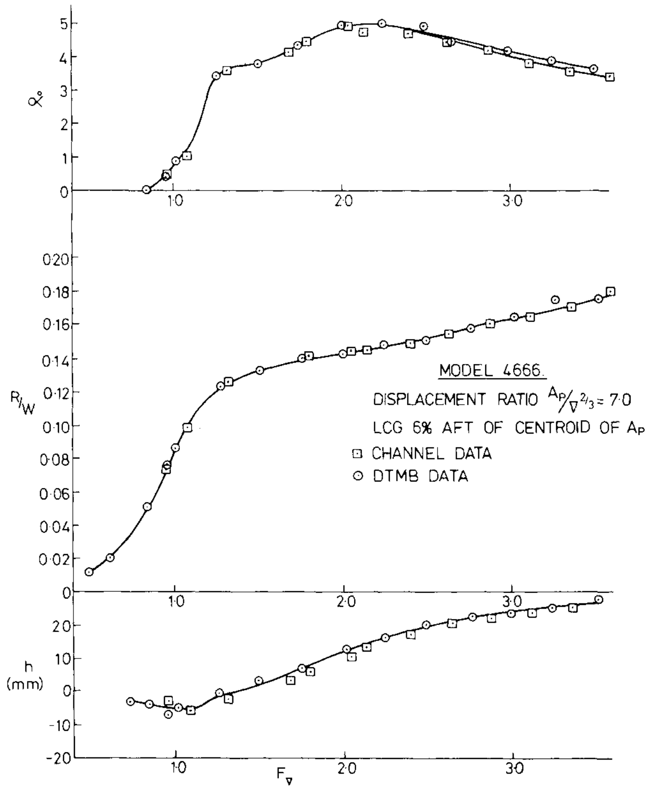

Fig. 5 Comparison of results obtained in the water channel and towing tank – model 4666, DTMB standard condition.

Discussion of Results

In order to compare the results obtained from the model tests in the water channel with the towing tank results, the possible effects of the restricted channel had to be considered. Information on the effects of channel dimensions over the required speed regime appeared to be scanty, since most of the data available, such as Refs. 5 and 6, are confined to the Froude numbers appropriate to displacement vessels. However, Toro[7] has measured the effects of shallow water on one of the hulls used in the present tests (model 4666). A correction was therefore applied to the results obtained in the channel, using a linear interpolation technique based on Toro's data, to obtain the deep water resistance for comparison with the towing tank data.

The curves for resistance (expressed as R/W), trim change α, and center of gravity change h against Froude number F_∇ are shown in Fig. 4 for the parent model (4667-1) and in Fig. 5 for the beamier model (4666) in the water channel and in the towing tank. In both cases, the curves, particularly of resistance, are effectively identical, particularly when the various possibilities for differences are considered, such as minor variations in model dimensions built to the same drawings and assumptions made in the normal scaling method. It was noted that for the displacement corresponding to the DTMB standard condition, the corrections due to shallow water effects were generally small. The maximum correction was approximately 7% on the residual resistance, which was of the order of 85% of the total resistance at that condition and occurred over a limited range of Froude numbers in the region $1.4 < F_\Delta < 1.9$. Outside this range of Froude numbers, the corrections were numerically smaller. Above $F_\nabla = 2.1$, the corrections were negative, showing that the effect of shallow water is to reduce the resistance below that for deep water in the planing regime. These results show that the data obtained in the water channel are consistent with

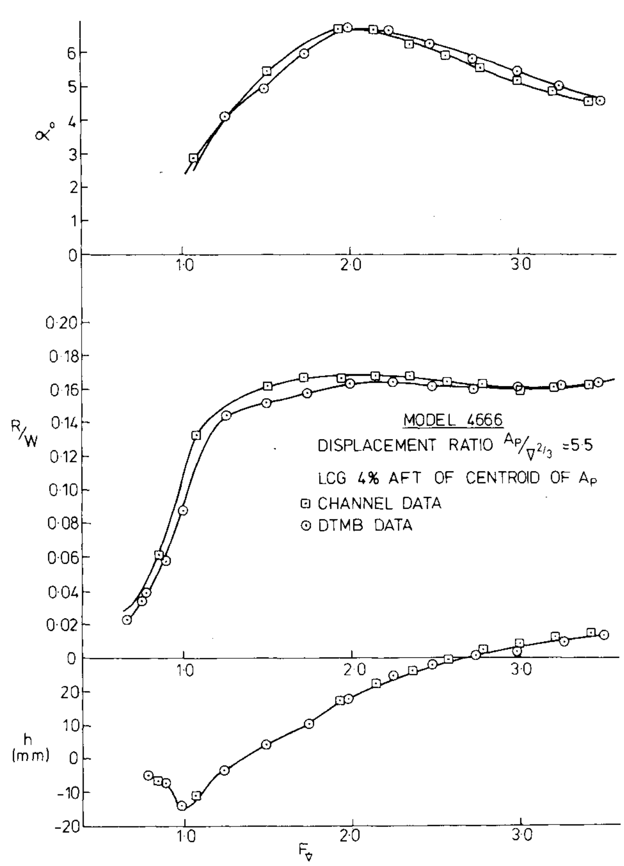

Fig. 6 Comparison of results obtained in the water channel and towing tank – model 4666 at a heavier displacement ($A_P/\nabla^{2/3} = 5.5$, LCG 4%).

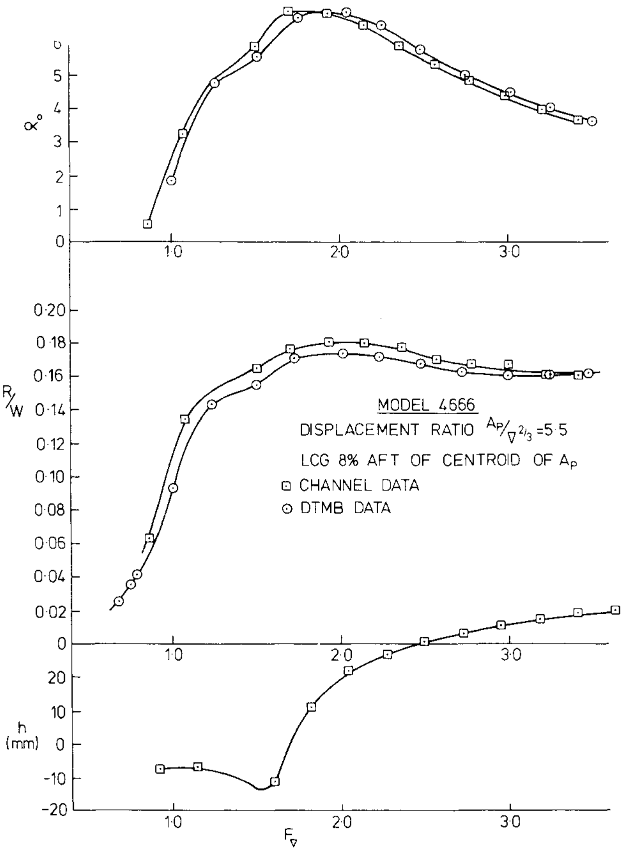

Fig. 7 Comparison of results obtained in the water channel and towing tank – model 4666 at a heavier displacement ($A_P/\nabla^{2/3} = 5.5$, LCG 8%).

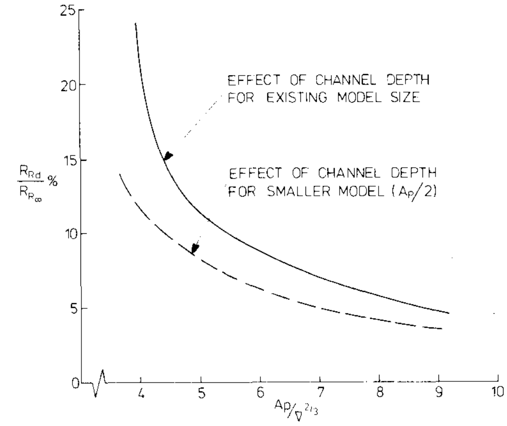

Fig. 8 The effect of displacement ratio on the shallow water correction.

data from the towing tank at the DTMB standard displacement ($A_P/\nabla^{2/3} = 7.0$), provided a correction is applied for shallow water effects.

At a heavier displacement ratio ($A_P/\nabla^{2/3} = 5.5$), the resistance measurements on model 4666 showed differences between the results from the water channel and the towing tank of 10-15% in the hump region. The results, after correction for shallow water effects using Toro's data, are shown in Figs. 6 and 7 for LCG positions 4% and 8% aft of the centroid of A_P. It can be seen that application of the shallow water correction has reduced the difference between the water channel and towing tank data by about half, resulting in differences of up to 6% in the region $1.1 < F_\nabla < 1.7$. Similar results were obtained at the two other LCG positions at this displacement. A comparison of the results for the heaviest displacement ratio ($A_P/\nabla^{2/3} = 4.0$) showed larger differences between the water channel and towing tank data, even after a shallow water correction had been applied.

It was, therefore, evident from these results, that with the existing model size ($L_P = 0.91$ m), the effect of channel dimensions increased with the larger displacement conditions and would not be satisfactorily accounted for by shallow water effects based on existing data for a displacement ratio

Table 2 Test conditions

Model	Displacement $A_P/\nabla^{2/3}$	LCG position % aft of centroid of A_P
4667-1	7.0	6
4666	7.0	6
	5.5	0, 4, 8, 12
	4.0	0, 4, 8, 12

less than the DTMB standard condition ($A_P/\nabla^{2/3} = 7.0$), i.e., for heavier models. The model size had been chosen with regard to towing tank experience, where it has been found difficult to obtain a turbulent boundary-layer flow on smaller models. However, subsequent experience has shown that in the water channel, a turbulent boundary can be more easily obtained at low Reynolds numbers. This has been attributed to the more uniform residual turbulence existing in the recirculating water channel. The predicted effect of shallow water corresponding to the channel depth for the present size of model is shown in Fig. 8. It can be seen that for the range of displacement ratios covered by the series 62 planing hull tests ($8.5 > A_P/\nabla^{2/3} > 4.0$), the correction ranges from 5% to 24%. The result of halving the planing area, giving a model length of 0.64 m, is also shown, and it can be seen that the shallow water effect is reduced to 10% at the lowest displacement ratio. It was also noted that the tests to determine the maximum permissible beam of model for the water channel (Ref. 4) were carried out with a light displacement model. It seems likely, therefore, that significant interference effects from the side of the channel may have been present with the two heavier displacement conditions of the present tests ($A_P/\nabla^{2/3} = 5.5$ and 4.0). Consequently, it is intended to investigate the possibility of using smaller models than in the present tests, in order to allow satisfactory measurements to be made at lower displacement ratios before restricted channel effects become significant.

It was also noted that Toro's data[1] was restricted to one hull model (model 4666) at a single displacement and three LCG positions. Toro has suggested that the effect of LCG position can be eliminated by expressing the results as a ratio of the shallow water to deep water residual resistance. It was found, however, that since Toro's measurements were carried out with the model free to trim the effects of trim, and hence LCG position, could not be entirely eliminated. Experience has also shown that in the hump speed regime it would be preferable to establish the shapes of the experimental curves more positively, in order to carry out an accurate interpolation technique. Thus it is intended to carry out a wider investigation into shallow water effects in order to produce data which can be applied generally to planing hulls. This will be carried out in the water channel, since the adjustable floor, used to obtain a flat water surface, can be moved vertically to allow the water depth in the working section to be progressively reduced from the maximum of 0.84 m down to 0.15 m depth.

Conclusions

A comparison of measurements made on two DTMB series 62 planing hulls (models 4667-1 and 4666) in the water channel, with results obtained in the towing tank, has shown satisfactory agreement for a displacement corresponding to the DTMB standard condition ($A_P/\nabla^{2/3}=7.0$), provided a correction is made for shallow water effects due to the restricted depth of the water channel.

At heavier displacements (lower displacement ratios), satisfactory agreement was not obtained. It is, therefore, intended to further investigate the possibility of using smaller models and also producing more comprehensive data on the effects of shallow water on planing hulls.

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