PERFORMANCE PREDICTION OF PLANING CRAFT USING TOWING TANK EXPERIMENTS

by

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1. Introduction

1.1 Hull form of ships and boats varies from one to the other unless they are "Sister Ships" of identical hull forms. The basic hull dimensions of length, breadth and depth are determined from owners requirements, e.g. sufficient volume to carry cargo/passengers etc. The subsequent draft will depend on the total displacement of the vessel. Within these fixed dimensions, it is possible to have any shape for the 3-dimensional surface of the hull of the ship. The total resistance of the vessel when in motion will be mainly governed by the hull shape or 'Lines' and also the propulsion characteristics since the hull shape has a distinct effect on the wake of water entering the propeller which will modify the propeller efficiency as compared to the open water propeller efficiency.

1.2 Determination of a suitable hull form for minimum resistance (and thereby reducing installed horsepower of propulsion engines and fuel consumption) is done on an empirical basis using existing similar hull shapes and their known resistance and propulsion characteristics and varying relevant parameters as necessary for the new design. So far there is no method by which the resistance of a particular hull could be calculated to an accurate degree. Thus the ship designer has to turn to ship models, which are towed at corresponding speeds using Froude's Law of Comparison to determine what the resistance would be for the prototype.

1.3 It became necessary to ascertain whether the hull form of a patrol boat designed by Colombo Dockyard Ltd. was capable of achieving the desired maximum speed with the installed horsepower of the propulsion engines. It was decided to obtain the services of the Towing Tank facilities of the Fluid Mechanics Laboratory of the Faculty of Engineering, University of Peradeniya for conducting towing experiments on a model of the boat for this purpose.

These tests are of a pioneering nature for several reasons. While a good deal of research has been done on ship resistance and propulsion of displacement type hull forms, relatively little work has been done on planing hulls. Further, till these experiments were conducted on this hull, the towing tank was mostly used for the calibration of river flow (current) meters and this application was an extension of the possible uses of the towing tank.

In this paper authors present the performance of the craft as predicted by towing tank experiments of the model and attempt to correlate this to actual performance of the prototype.

2. Nomenclature

g – Acceleration due to gravity, m/s^2
t – Temperature, ^{0}C
S – Wetted surface area, m^2
V – Velocity of craft, m/s
S^1 – Modified wetted surface area, m^2
F_r – Froude Number based on length
R_a – Air resistance, N
R_{app} – Appendage Resistance, N
R_e – Reynolds Number
R_f – Frictional Resistance of naked hull, N
R_t – Total Resistance, N
R_w – Wave making resistance, N
V_a – Velocity of air relative to craft, m/s
Δ – Displacement, Tonnes

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λ – Froude Frictional Coefficient
ρ – Density of Working liquid, kg/m³
ρ_a – Density of Air, Kg/m³
μ – Viscosity of working liquid, N s/m²
μ_a – Viscosity of air.
γ – Specific weight of water N/m³

Suffixes m – model
p – prototype

3. Theoretical Basis for Prediction

3.1 The total resistance R_t to the motion of a partially immersed body may be written non dimensionally as.

$$\frac{R_t}{\rho g L^3} = f\left(\frac{V}{\sqrt{gL}}, \rho\frac{VL}{\mu}, \rho_a\frac{V_a L}{\mu_a}\right) \quad \text{----------(1)}$$

where f is a function dependent on the Geometrical shape of the body. It is practically impossible to vary Froude number and Reynolds number $\left(\rho\frac{VL}{\mu}\right)$ independently to obtain full dynamic similarity between model an prototype.

It is however reasonable to assume that the three mechanisms giving rise to the total resistance are almost independent (Froude's Law of comparison) and write

$$\frac{R_t}{\rho g L^3} = f_1\left(\frac{V}{\sqrt{gL}}\right) + f_2\left(\rho\frac{VL}{\mu}\right) + f_3\left(\rho_a\frac{V_a L}{\mu_a}\right) \quad \text{----------(2)}$$

f_1 which represents the wave making resistance (Rw) cannot usually be calculated to any degree of accuracy. f_2 represents the frictional resistance of the naked hull (Rf) and the frictional resistance of the appendages Rapp) such as propeller shafts, rudders etc. It is possible to calculate both R_f and R_{app} to a fair degree of accuracy from the large amount of data available. f_3 represents the air resistance (Ra) which can also be calculated and which, in the context of the speeds encountered in the present study, can be ignored for still air conditions.

3.2 In the model test, which is carried out by maintaining the same Froude number in the model and the prototype. only the wave making resistance will be modelled. i.e..

$$\frac{V_m}{\sqrt{g L_m}} = \frac{V_p}{\sqrt{g L_p}} \quad \text{-----------(3)}$$

$$\frac{R_{wm}}{\rho_m g L_m^3} = \frac{R_{wp}}{\rho_p g L_p^3} \quad \text{-----------(4)}$$

The towing tank test will measure R_{tm} where

$$R_{tm} = R_{wm} + R_{fm} + R_{app.m} \quad \text{......——(5)}$$

neglecting R_{am}, R_{fm} may be calculated from (ref. 1)

$$R_f = \frac{\gamma\lambda S V^{1.825}}{1000} \quad \text{........(6)}$$

The frictional coefficient has been empirically determined for various lengths of ships and models and has to be corrected for the temperature of the working liquid (reference 1).

There are methods of estimating the resistance of appendages that are always fully submerged. It is also possible to determine R_{app} by testing the model with and without appendages. As R_{app} is sometimes calculated using $V^{1.825}$, it would probably be most convenient to increase the wetted surface area from S to S^1 to take into account R_{app}.

S^1 was computed after testing the model with and without appendages. Then,

$$R_{app} + R_f = \frac{\gamma\lambda S^1 V^{1.825}}{1000} \quad \text{...........(7)}$$

R_{wm} can now be determined by subtracting $R_{app}+R_f$ from the measured value of R_{tm}. R_{wp} can now be obtained from (4). R_{tp} can now be calculated from

$$R_{tp} = R_{wp} + \frac{\gamma\lambda_p\, S^1_p\, V^{1.825}}{1000} \quad \text{...........(8)}$$

$$\text{where } S^1_p = \left(\frac{Lp}{Lm}\right)^2 S^1_m \quad \text{...........(9)}$$

and γ will be the specific weight of sea water.

3.3 Estimation of Propulsive Power required :

Once R_t is calculated for the prototype, then

$$\text{effective power } (P_E) \text{ required} = \frac{R_t \times V \times 0.5144}{75} \text{ hp}$$

where R_t is in Newtons
V is in Knots (1 Knot = 0.5144 m/s)

The actual total shaft horse power required of propulsion engine is (P_s) given by

$$P_s = \frac{P_E}{\text{Nmech} \times \text{Np}}$$

where Nmech = mechanical transmission efficiency
Np = behind hull propeller efficiency

It is this value P_s which can be used to correlate the performance of model and prototype since the total resistance of the potoype cannot be measured directly.

4. Towing Tank and Towing Mechanism

4.1 The towing tank facility at the University of Peradeniya was used for the towing tests. The towing tank is 55 m long and 1.83 m wide. The water depth was maintained at 1.25 m in the measuring section. The towing carriage is powered by an onboard Ward Leonard system and is capable of accelerating and maintaining speeds upto 3 m/s for duration of 10 seconds or more.

4.2 The towing mechanism is shown in Plate I. The tow bar is hinged at either end and attached to the model on an axis vertically above the centre of floatation. The tow bar was attached above the waterline because of the possibility of interference between the towing mechanism and the trimming action of the model in motion. The tow bar was horizontal.

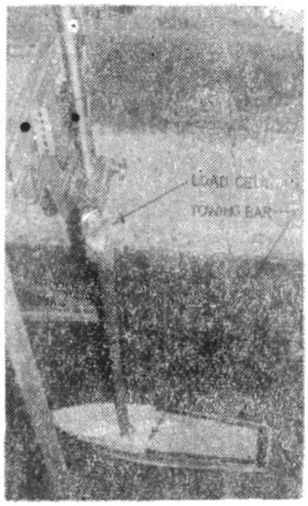

PLATE 1
Arrangement of Load Cell and Towing Bar

5. The Model

5.1 The model was shaped from a single block of teak and its outer surface was painted and polished. The propeller shafts, p-brackets and rudders (later referred to as appendages) were also modelled.

Tank tests were carried out on the model both with and without appendages.

Initially the model was made identical to the prototype upto the deck line with sheer etc., but subsequently to obtain the required displacements model weight had to be further reduced. The top surface therefore was cut off making it parallel to load water line. This has no effect on the resistance tests except perhaps for air resistance.

5.2 Weights were attached to bring the model to the correct weight computed using the scale ratio and the density ratio between fresh water and seawater. The contribution made by the weight of the tow bar was taken into account. The load water line was marked on the model and the weight were shifted to obtain the correct trim.

6. Instrumentation

6.1 The load cell was arranged so that the towing force was transmitted by four vertical webs machined from a block of brass. Two webs were in tension and the other two in compression. Strain gauges attached to the webs were connected in a four-arm bridge to obtain maximum sensitivity and to cancel out thermal effects. The strain gauges were connected to a strain-gauge bridge amplifier and the out of balance voltage was read. The cell was calibrated by static loading before and after each run. The cell proved to be reliable and no hysterisis or drift was observed within the normal working range of the tests. The cell was insensitive to vertical loads.

6.2 The speed of the carriage was measured from a speedometer which was in turn calibrated using a carefully machined measuring wheel attached to the carriage.

The measurements of speed and towing force were accurate to within one percent.

6.3 Speed measurement of the prototype was done using a rotating vane-operated speedometer fitted to the hull bottom which indicated the speed in knots through a moving coil galvanometer.

The speedometer was calibrated by timing known distances traversed using Navigational charts.

7. Performance

7.1 The results of the towing test carried out with and without appendages equivalent to $\Delta_p = 45T$ shows that R_t and R_{app} could be calculated together by increasing the wetted surface area to $S^1 = 1.16S$.

7.2 Figure 1 shows the variation of total resistance of model with speed at normal trim for displacements corresponding to $\Delta_p = 38$, 40 and 45 T. It is seen from the slope of the curves that planing commences around 1.4 m/s but that full planing (with a reduction of total resistance) is not achieved within the speeds tested.

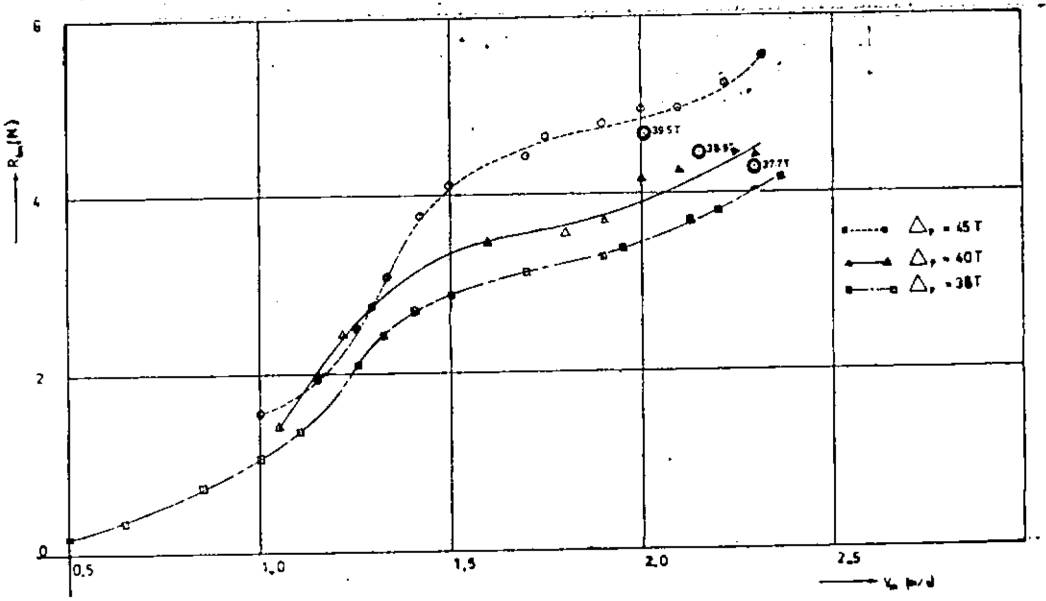

Figure 1 : VARIATION OF TOTAL RESISTANCE OF MODEL WITH SPEED FOR THREE DISPLACEMENTS AT NORMAL TRIM

Figure also shows three points corresponding to the measurements taken on the prototype converted back to this model scale by reversing the calculation procedure given in section 3.

The optimum propeller efficiency (0.63) was used in determining the thrust delivered by the propeller. It should be noted that should the propeller efficiency have been lower than the optimum, the actual resistance of the prototype would be lower than that indicated. This would cause the 3 points to move closer to the corresponding displacement curves for model. The percentage deviation of predicted resistance from the actual is approximately 12 % (average). It is thought that laminar flow around the model leads to lower resistance values than would be under turbulent flow conditions specially in view of the small model size.

It is intended to use trip wires in the future on models of this size to ensure that flow past the model would be fully turbulent and hence correspond closer to the actual conditions for prototype.

7.3 Figure 2 shows the variation of total resistance of model with speed for 3 static trims. It indicates that increased trims by stern produces higher resistance.

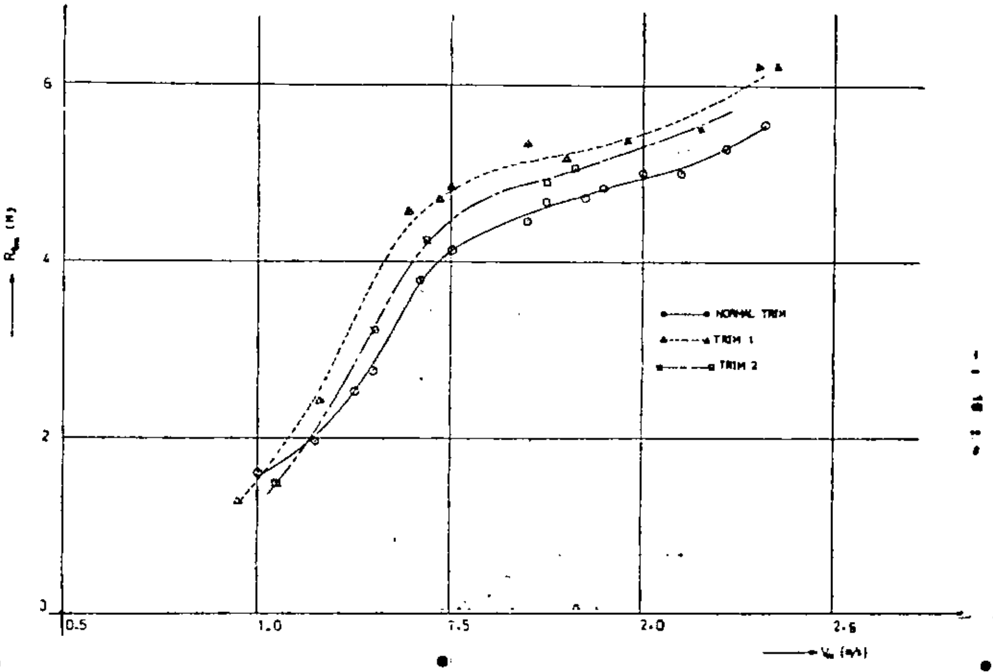

Figure 2 : VARIATION OF TOTAL RESISTANCE OF MODEL WITH SPEED FOR THREE TRIMS

which could be caused by a tendency to squat due to the high speed planing area in the after portion of the hull bottom being skewed. Trim 1 corresponds to an aft draught increase of 0.02 inches (0.508 mm) and Trim 2 to an aft draught of 0.05 inches (1.29 mm). It is to be noted that for Trim 2 the resistance is less than for Trim 1 which may be due to a more favourable angle of attack of the aft plane.

7.4 Plates 2 and 3 show the wake of the prototype and the model respectively. A marked "rooster tail" appears in both cases. This is probably due to the skewed, after hull bottom. Plate 4 shows the model's wake with a transom flap fitted to hull. The flap is an extension of the hull bottom shape at transom. The rooster tail is absent.

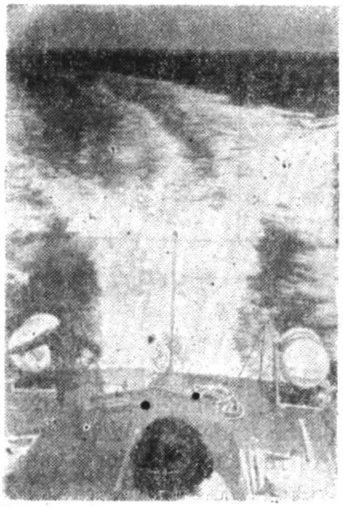

PLATE 2 Wake of Prototype at Speed

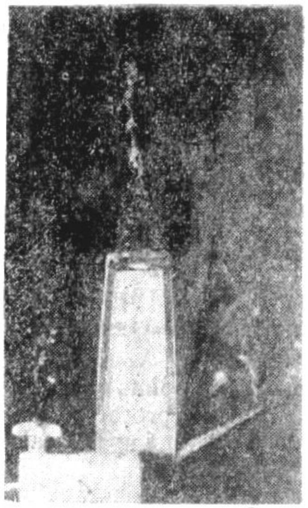

PLATE 3 Wake of Model at $V_m = 2.45$ m/s ($\Delta_p = 40T$)

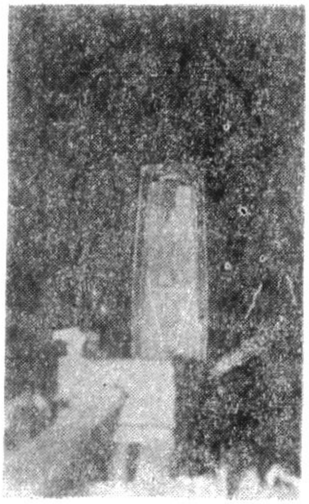

PLATE 4 Wake of Model with Transom Flap at $V_m = 2.45$ m/s ($\Delta_p = 40T$)

Figure 3 shows the remarkable reduction in resistance obtained after fixing the transom flap. This reduction is thought to be caused by the "ironing-out" effect of the flap and the consequent reduction in energy dissipated in the rooster tail.

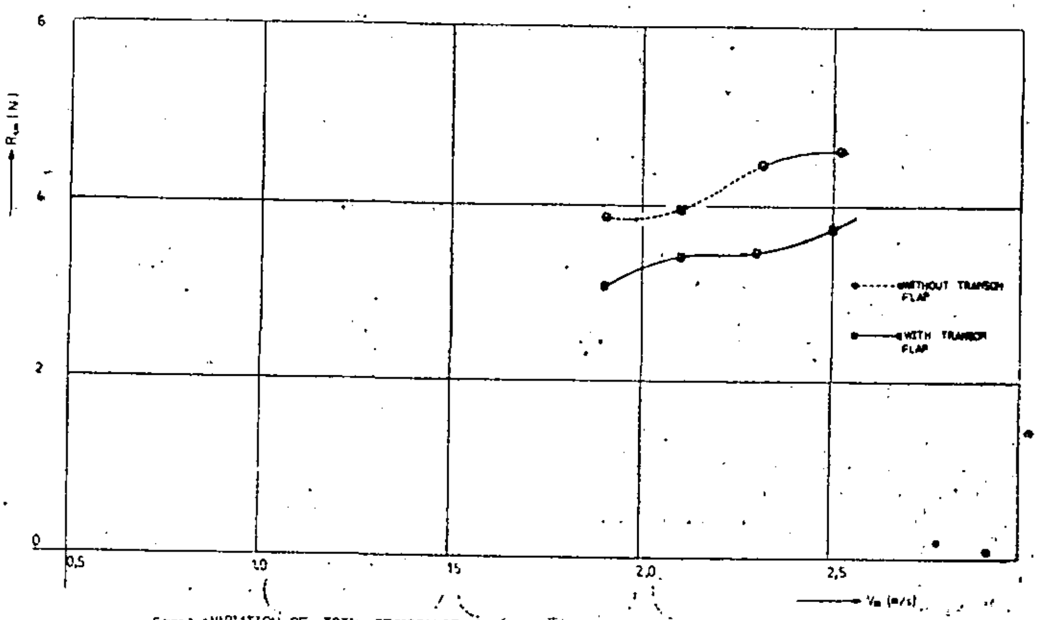

Figure 3 : VARIATION OF TOTAL RESISTANCE OF MODEL WITH SPEED, WITH AND WITHOUT TRANSOM FLAP [FOR Δ_p = 60T]

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8. Other Considerations

8.1 Static wetted surface area of the craft has been used in the computations. The wetted surface area when the craft is in motion, would be different from the assumed area due to planing action unlike in displacement—type hulls. This would have introduced some error to the computations.

8.2 The model was towed by the towing bar in a horizontal position, the pivot being closely located directly above the static centre of floatation. This also would have introduced some error since for correct simulation, the model should be towed by applying the towing force along the axis of the propeller shaft as otherwise the model would not have the freedom to trim to its natural position. A method is being devised to tow future models in this manner. Even then some degree of error will always arise since due to planing the shaft angle relative to the towing mechanism will change.

8.3 In the prototype, the superstructure offers an appreciable windage area which is absent in this model. Even on the prototype, the wind force will be small in calm weather at the speeds involved.

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References

1. "Fundamentals of Ship Resistance and Propulsion" published by the Netherlands Ship Model Basin.
2. "Ships and Naval Architecture" by R. Munro Smith 1973.
3. "Naval Architecture of Planing Hulls" by Lindsay Lord, 1954.
4. "Resistance Tests of a Systematic Series of Planing Hull Forms" by E. P. Clement and D. L. Blount. Transactions for 1963 of S.N.A.M.E., Vol. 71.