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RESISTANCE PREDICTION OF PLANING CRAFT FROM SIMILAR CRAFT USING THE ALMETER METHOD

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SUMMARY

This paper presents a method for developing resistance prediction techniques and predicting calm water resistance for planing craft using empirical data from a parent of different proportions and loadings. This method can increase the accuracy of the prediction, decrease the amount of model testing required and simplify resistance prediction algorithms. Examples are given for several different planing craft over a wide speed range.

AUTHOR'S BIOGRAPHY

Mr John Almeter is a naval architect with the Combatant Craft Design Group of the Naval Surface Warfare Center of the United States Navy. He supports a wide range of craft including, landing craft, tugs, patrol boats, rigid hull inflatables, utility, crew and work boats from requirements definition to construction to in-service engineering. Mr Almeter received his bachelor of engineering in naval architecture and marine engineering from the University of Michigan in 1983 and he has authored several papers on planing hull resistance prediction.

NOMENCLATURE

A_n	Almeter number, $\Delta/(1/2\ \rho\ \text{LCG}\ B_m\ V^2)$ (non-dimensional)
$A_p/\nabla^{2/3}$	Load coefficient (non-dimensional)
B	Beam
B_m	Chine beam
C_f	Frictional coefficient (non-dimensional) based on Reynolds Number
C_n	Clement number, $\nabla/(\text{LCG}^2 B)$ (non-dimensional)
C_Δ	Beam loading, $\nabla/B_m{}^3$ (non-dimensional)
$F_{n\nabla}$	Volumetric Froude Number, $V/(\nabla^{1/3}\ g)^{1/2}$ (non-dimensional)
F_{nv}	Volumetric Froude Number (non-dimensional)
g	Gravitational constant
L	Length
L/B	Length to beam ratio (non-dimensional)
LCG	Longitudinal center of gravity from the transom
L_p	Chine length
R	Resistance
R/Δ	Resistance to weight ratio (non-dimensional)
R/W	Resistance to weight ratio (non-dimensional)
S	Wetted surface
V	Velocity (Advance speed)
$V/L^{1/2}$	Dimensional speed length ration (knots/ft$^{1/2}$)
W	Weight
ρ	Mass density
Δ	Weight
τ	Trim
δ	Weight density
∇	Displacement (volume)

1. BACKGROUND

Boat builders and designers have long been frustrated by their inability to predict the performance of a design from data of a "similar" boat (parent craft) of different proportions or loadings. Traditionally, naval architects have used the Froude Method to extrapolate the performance of one boat from the empirical data obtained at full scale or from model testing of another craft of similar characteristics. Naval architects often resort to planing craft predictions derived from a craft that has a different style hull than the craft for which the prediction is being made.

Proper Froude scaling has very strict requirements that are often impossible to meet with the existing model or full size data of the "similar" boat. This can degrade the value of the prediction. The data of the "similar" boat may therefore be unusable or misleading. This paper presents a method that allows the designer to improve the prediction on an existing boat that is "similar" but of different proportions or loadings.

2. FROUDE METHOD

The Froude Method is often used for the resistance prediction of planing craft. This approach requires that the parent and craft for which the prediction is being made are geosims having the same:

- Hull Form (Body plan, deadrise, etc.)
- Proportions (L/B)
- Loading (C_Δ, $A_p/\nabla^{2/3}$, etc.)
- LCG Location (LCG/L_p, trim (τ), etc.)
- Speed (Froude Number, Speed Length Ratio)

Planing hull series typically use a large test matrix of hundreds of cases (runs) to allow for accurate interpolation of resistance. Empirical methods based on these large matrices require equations with dozens of terms for each speed. Resistance at intermediate speeds is determined by interpolation. All told, hundreds of terms are required for the entire speed range.

A large test matrix of data of a parent, which exactly matches the craft of interest, may not exist. Very little high quality systematic data is available in the public domain on modern planing craft [1]. It is often not economically feasible to perform extensive model testing for a specific hull. This is especially true early in the design when the dimensions and loadings of the craft are likely to change.

3. ALMETER METHOD

3.1 INTRODUCTION

A parametric method for resistance prediction based on model or full size testing is presented in this paper based on only two non-dimensional variables. The method is valid for craft with similar body plans. Fewer variables are used in this method than in the Froude Method. The variables selected are independent of hull proportions which allows the prediction to be based on a parent craft with different length to beam and beam to draft ratios.

The paper builds on the work previously published in Almeter [2] and Clement [3]. In Almeter [2] the resistance of similar planing craft of different proportions and loadings was shown to reduce to only one non-dimensional variable at planing speeds. Clement [3] showed that the maximum "hump" resistance of similar craft of different proportions and loadings could also be reduced to a single variable. This paper uses both the Almeter and Clement variables for resistance prediction from slow speed displacement to high speed planing in a single equation or chart.

3.2 ALMETER NUMBER, A_n

The planing resistance prediction of planing craft of similar body plan over a wide range of L/B ratios, loadings and LCG locations can be made based on the testing of a single model or full size craft at a single load condition using the (non-dimensional) Almeter Number, A_n, which is defined as:

$$A_n = \Delta / (1/2\, \rho\, LCG\; B_m\; V^2) \qquad (1)$$

Where:

B_m = Chine beam
LCG = Longitudinal center of gravity from the transom
Δ = Displacement, weight
ρ = Mass density
V = Velocity (Advance speed)

Both Almeter [2] and Clement [3] provide numerous examples supporting the use of the Almeter Number for planing craft at planing speeds. Fig. (1), taken from Almeter [2], plots the resistance of Series 62 [4] planing craft, with different length to beam ratios, non-dimensional loadings and longitudinal center of gravity, at planing speeds using the Almeter Number. Decreasing Almeter Numbers correspond to increasing planing speeds because the velocity is in the denominator. The data from these diverse conditions essentially collapses to a single line. This is in contrast to the same data shown in Figs. (2) and (3) also from Almeter [2], where the data is plotted using the dimensional speed length ratio (knots/ft$^{1/2}$) and Volumetric Froude Number (Froude Method). These plots diverge with the Froude Method with increasing speed and are highly dependent on loading and LCG location.

3.3 CLEMENT NUMBER

Clement [3] shows that the maximum hump non-dimensional resistance of a systematic family of planing craft compresses to a single line that is a function of the (non-dimensional) Clement Number as shown in Fig. (4) taken from Clement [3]. The Clement Number, C_n , is defined as:

$$C_n = \nabla / (LCG^2 B_m) \qquad (2)$$

Where:

B_m = Chine Beam
LCG = Longitudinal center of gravity from the transom
∇ = Volumetric displacement

Higher C_n corresponds to higher loading. The C_n is useful for predicting and avoiding high hump drags. However, the speed where the maximum hump speed occurs is not well defined, Clement [3].

3.4 ALMETER AND CLEMENT NUMBERS (A_n & C_n) TOGETHER - *ALMETER METHOD*

An approach has been developed where both the Almeter Number, A_n, and Clement Number, C_n, are used to predict resistance as shown in Fig. (5). The logarithm of A_n is used for the horizontal axis to provide a more readable plot of data and to simplify curve fitting. In this logarithmic representation decreasing (negative) values of the log of A_n correspond to higher planing speeds.

Several C_n are plotted ranging from very light to very heavy loadings. From $\log(A_n)$ of 0.0 and higher, the craft is in the displacement mode. The hump regime ranges from $\log(A_n)$ of -1.0 to 0.0. Planing is from $\log(A_n)$ of -1.0 and lower. In the hump and displacement range, the non-dimensional resistance, resistance divided by weight (R/W), generally increases with increasing C_n. The R/Δ may decrease slightly at extreme values of Clement Number as $\text{Log}(A_n)$ approaches -1.0. At values of $\log(A_n)$ of -1.0 and below (planing regime), R/Δ is predominantly a function of A_n. Craft with very small values of C_n, lightly loaded, have slightly smaller values of R/Δ at speeds approaching $\text{Log}(A_n)$ of -1.0.

The resistance of planing hulls starts to increase significantly at $\log(A_n)$ under -1.5. At these very high speeds the hull resistance is predominantly skin friction. Offshore racing boats and other high speed planing craft may operate in this speed range. Without realising it, the designers of these craft try to keep A_n from becoming too small by keeping the LCG well aft (small LCG) and by using longitudinal spray rails and pads (small beam). This reduces drag.

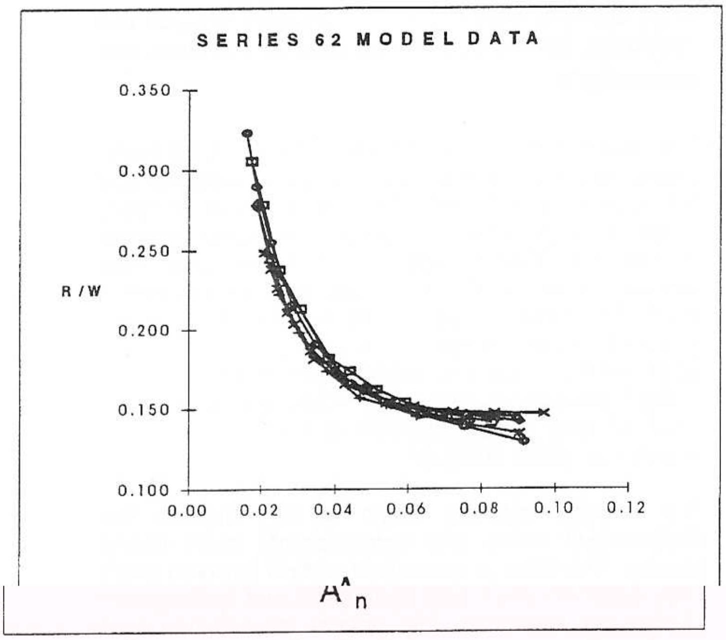

Fig. 1 Plotting of R/W Using A_n

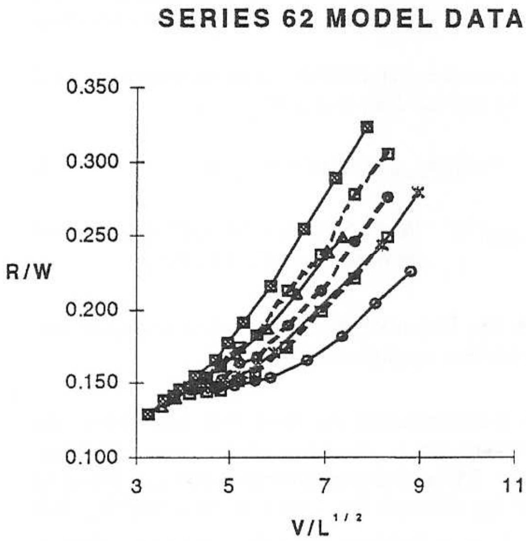

Fig. 2 Plotting of R/W Using Froude Method

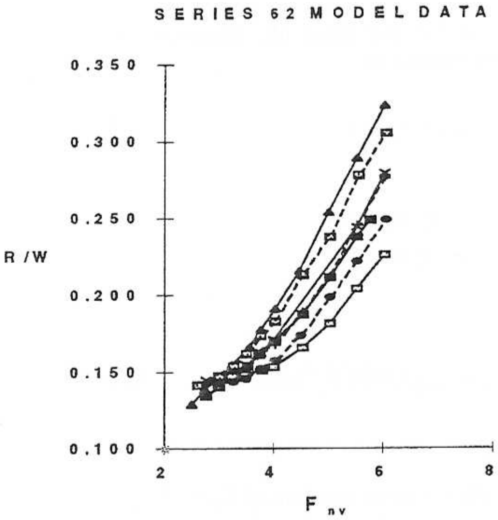

Fig. 3 Plotting of R/W Using Froude Method

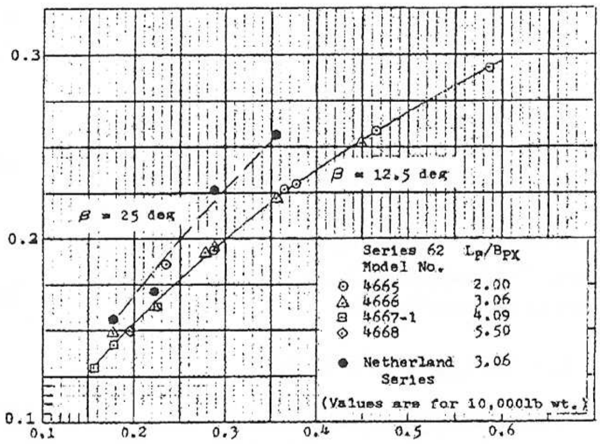

Fig. 4 Maximum R/W Versus C_n $(\nabla/(LCG^2B_m))$

Dynamic trim and wetted surface can also be presented using the Almeter Method using the A_n and C_n as shown in Figs. (6) and (7). Both the trim and wetted surface form a smooth family of curves. The trim shown is the total trim with respect to the craft's keel. The wetted surface has been non-dimensionalized with respect to LCG and chine beam. At high planing speeds trim and wetted surface are predominantly a function of A_n for a given hull form as previously shown in Almeter [2]. In the hump range the trim and wetted surface is a function of both A_n and C_n. The wetted surface increases at the lower speed end of the hump range (larger A_n). The non-dimensional wetted surface increases with decreasing C_n. At low displacement speeds the trim is essentially the static trim and the wetted surface is the static wetted surface.

3.5 DERIVATION OF THE ALMETER METHOD

When using this proposed method, both wetted surface and trim need to be expressed as a function of Almeter and Clement Numbers, A_n and C_n. The bare hull resistance is then treated predominantly as a function of speed, wetted surface and trim. The following simplified derivation demonstrates how the Almeter Method works. The hull resistance of a planing craft is approximately:

Resistance = skin friction + pressure drag (3)
(spray and air drag neglected)

$$R = 1/2\rho\, C_f\, S_{LCGB}\, LCG\; B\; V^2 + f_0 \operatorname{Tan}(\tau)\, \Delta \tag{4}$$

Where: S_{LCGB} = Wetted surface non-dimensionalised with respect to LCG and B.

C_f is the Reynolds dependent (non-dimensional) skin friction coefficient.

f_0 is a (non-dimensional) function that addresses the differences between a prismatic shape and an actual planing craft. For a simple prismatic shape it is equal to one. It will be different for cases of bow wetting, hull warp, etc. f_0 is a function of body plan (hull shape), Almeter and Clement Numbers. Equation (4) can be rewritten as:

$$R/\Delta = C_f\, S_{LCGB} / A_n + f_0 \operatorname{Tan}(\tau) \tag{5}$$

The trim, τ, and non-dimensional wetted surface, S_{LCGB}, are predominantly a function of A_n and C_n for a given body plan as will be shown in the derivation and the data to follow.

At small values of A_n, high speed planing, the lift is almost entirely dynamic and buoyant forces are not significant. Conversely, at displacement speeds the lift is predominantly buoyant. At the hump speed both dynamic lift and buoyant forces are significant. The C_n dictates the influence of the hydrostatic forces at the hump speed. The buoyant lift, Δ_b, of a trimmed prismatic planing surface is proportional to:

$$\Delta_b \sim 1/2(S_{LCGB}\, LCG)^2 B \operatorname{Tan}(\tau)\, \delta \tag{6}$$

Where: δ = weight density

This basic relationship is given in Saunders [5] and numerous other references. The non-dimensionalized wetted surface above is a function of A_n and C_n in the hump speed regime. Equation (6) can be rewritten as:

$$\Delta_b / (1/2(S_{LCGB}\, LCG)^2 B\, \delta) \sim \operatorname{Tan}(\tau) \tag{7}$$

If it is assumed that buoyant forces support the entire weight of the prismatic surface, the above equation can be rewritten as:

$$C_n / S_{LCGB}^{\;2} \sim \operatorname{Tan}(\tau) \tag{8}$$

C_n is one of the two variables used in the Almeter Method. Trim increases with increasing C_n where the buoyant forces are significant for the prismatic shape. Increasing trim increases the pressure drag and accordingly the total drag of the prismatic shape. Higher C_n results in higher non-dimensional drag in the hump range due to its higher trim. The influence of C_n on trim decreases, however, as the dynamic lift increases with decreasing A_n.

The smaller trims associated with lower C_n in the hump range, results in reduced proportional dynamic lift and increased relative buoyant lift. For a simple prismatic shape of infinite length, the center of dynamic pressure is near the forward edge of the wetted area, thus average wetted length. As a result the average wetted length for a high-speed planing surface is not much greater than the distance of the LCG from the transom as shown in Fig. (8). The wetted length of a trimmed box sitting in the displacement mode of infinite length is three times as long as the distance of the LCG from the transom as shown in Fig. (9).

The average waterline length is very high in the displacement mode and comparatively short during planing. The average water-line length is between these two extremes when both hydrostatic and hydrodynamic forces are significant. The greater the relative significance of the hydrodynamic forces, the shorter the average waterline length. Proportionately the hydrodynamic forces are smaller for small C_n values in the hump range due to their smaller trims. This results in higher S_{LCGB} at lower values of C_n in the hump range.

A simplified equation for the total lift, buoyant plus dynamic, of a planing surface is:

$$\Delta_b + \Delta_d = \Delta \tag{9}$$

Where:

Δ_b = buoyant lift
Δ_d = dynamic lift

Buoyant lift is;

$$\Delta_b = 1/2\, f_1 (S_{LCGB}\, LCG)^2 B \operatorname{Tan}(\tau)\, \delta \tag{10}$$

Where:

f_1 is a non-dimensional function of C_n and A_n for a given hull shape.

The dynamic lift is more complex. The following equation is from the classic Savitsky paper [6] and numerous other references.

$$\Delta_d = 1/2\, \rho\, C\, \lambda^{1/2} \tau^{1.1}\, V^2 B_m \tag{11}$$

Where: C = (non-dimensional) constant
λ = wetted area divided by beam squared (non-dimensional)

If tan (τ) is substituted for $\tau^{1.1}$ and the equation is re-written in terms of A_n and S_{LCGB} the following equation is derived.

$$\Delta_d = f_2\, \Delta\, (B_m/LCG)^{1/2}\, S_{LCGB}^{\;1/2} \operatorname{Tan}(\tau) / A_n \tag{12}$$

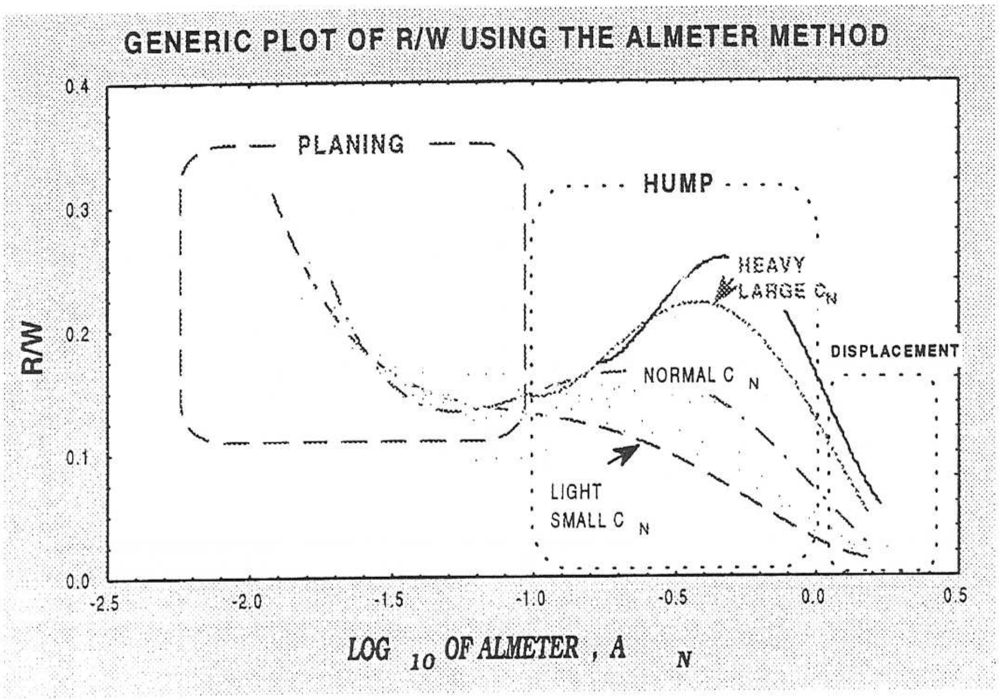

Fig. 5 Generic Plot of R/W Using Almeter Method

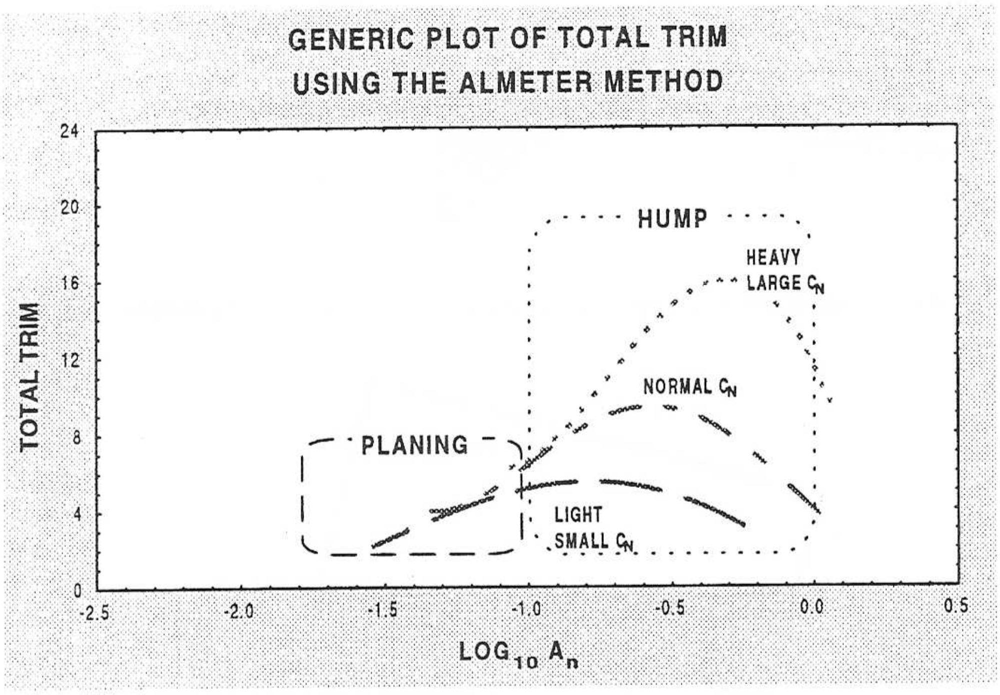

Fig. 6 Generic Plot of Trim Using the Almeter Method

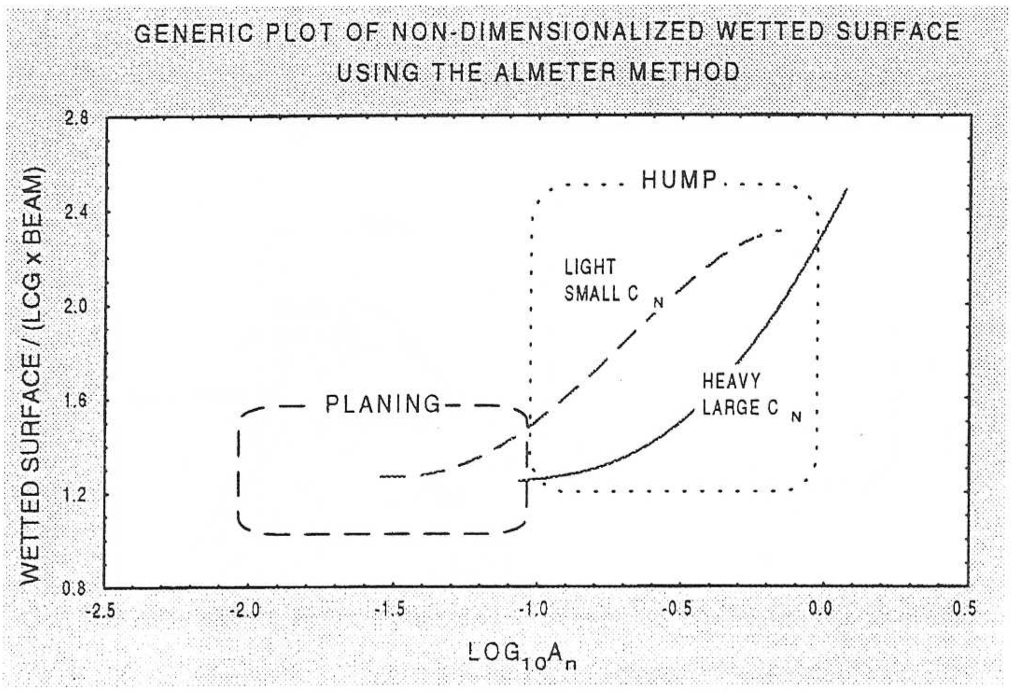

Fig. 7 Generic Plot of Wetted Surface Using the Almeter Method

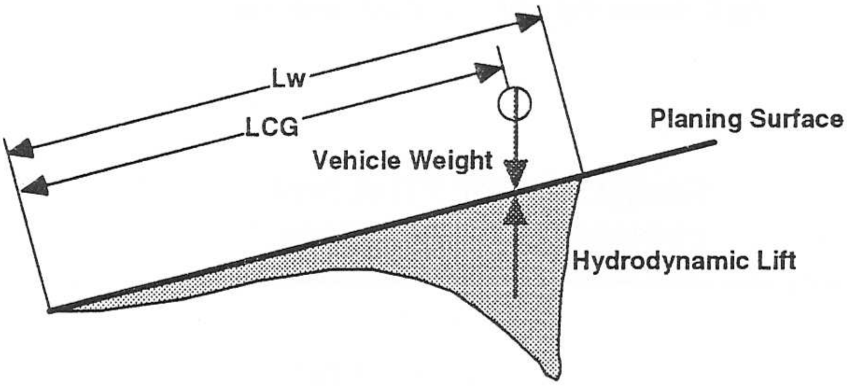

Fig. 8 Relationship of Average Wetted Length and LCG on a Typical Planing Surface

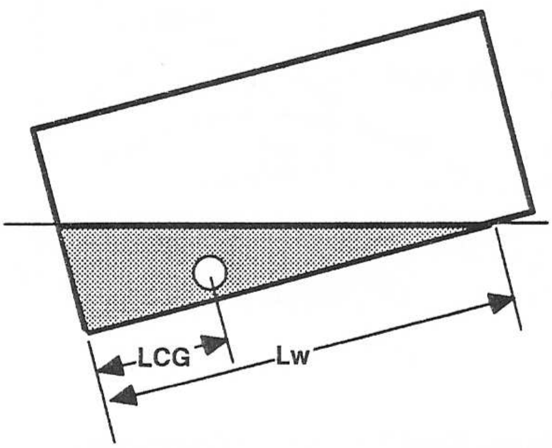

Fig. 9 Relationship of Wetted Length and LCG on a Floating Box

f_2 is a non-dimensional function of C_n and A_n for a given hull shape. For small ranges of C_n and A_n they can be considered constants. The relationship of τ on Δ_d is approximate. Combining the equations (10) and (12) yields;

$$\Delta = 1/2\, f_1 (S_{LCGB}\, LCG)^2 B\, Tan(\tau)\, \delta + f_2\, \Delta\, (B_m/LCG)^{1/2}$$

$$S_{LCGB}{}^{1/2} Tan(\tau) / A_n \qquad (13)$$

Substituting C_n in the hydrostatic term and dividing by $Tan(\tau)$ and Δ results in equation (14) below.

$$1/Tan(\tau) = 1/2 f_1\, S_{LCGB}{}^2/C_n + f_2 (B_m/LCG)^{1/2} S_{LCGB}{}^{1/2}/A_n \qquad (14)$$

Using the same approach for the longitudinal moments results in:

$$1/Tan(\tau) = 1/2 f_3\, S_{LCGB}{}^3/C_n + f_4 (B_m/LCG)^{1/2} S_{LCGB}{}^{3/2}/A_n \qquad (15)$$

f_3 and f_4 are non-dimensional functions of C_n and A_n for a given hull shape. For small ranges of C_n and A_n they both can be considered constants.

By combining equations (14) and (15) $Tan(\tau)$ can be reduced as below.

$$1/2 f_1\, S_{LCGB}{}^2/C_n + f_2 (B_m/LCG)^{1/2} S_{LCGB}{}^{1/2}/A_n - 1/2 f_3$$

$$S_{LCGB}{}^3/C_n - f_4 (B_m/LCG)^{1/2} S_{LCGB}{}^{3/2}/A_n = 0 \qquad (16)$$

In this derivation the trim and non-dimensional wetted surface are a function of C_n, A_n and B_m/LCG for a given hull form. The objective is to eliminate B_m/LCG as a variable. At high planing speeds (very small A_n) it can be seen by inspection that B_m/LCG and C_n can be eliminated from equation (16). The second and fourth terms become extremely large in high speed planing due to A_n becoming very small in denominator. This allows the first and third terms of equation (16) to be neglected. This allows A_n and $(B_m/LCG)^{1/2}$ to be eliminated from the equation. This leaves S_{LCGB} as a constant, which is the common observation. Inspection of equations (13) and (14) also shows that B_m/LCG and C_n will also have a small effect on the running trim at high planing speeds (small A_n).

At high planing speeds the resistance is predominantly a function of friction and not pressure drag (trim). This allows B_m/LCG and C_n to be neglected at the higher planing speeds, Almeter [2]. This still leaves the hump and displacement modes. R/W is plotted as a function of A_n for a bands of the C_n in Figs. (10-13) for the American Series 62, Clement [4], Technical University Nova Scotia Series, Delgado-Salsdivar [7] and the Dutch Series 62, Keuning [8]. Within the bands the B_m/LCG and LCG/L_p vary greatly. Based on the minimal overlap between the bands, it is evident that B_m/LCG and LCG/L_p are minor variables in comparison with A_n and C_n in the hump and displacement speed ranges. The same can be said for trim and wetted surface in Figs. (14) and (15).

A small change in a minor variable will not significantly affect R/W. However, a large change of a minor variable may have a significant effect on R/W. This is the case with B_m/LCG. Detailed review of the cited series and the Soviet BK and MBK series, Almeter [9], shows that large B_m/LCG planing craft tend to have greater hump drag than low B_m/LCG planing craft for a given C_n and A_n in the hump range. The effect of the B_m/LCG depends on how much it varies and C_n. At the extremes, B_m/LCG impacted R/W as much as 0.04 R/W at the hump.

One approach to minimize the error at the hump is to express R/W as a function of C_n and $(B_m/LCG)^{1/2}/A_n$. This new variable can also be rewritten as $\Delta/(1/2\rho\, LCG^{1/2} B_m{}^{3/2} V^2)$. This allows S_{LCGB} and trim in equations (13), (14) and (16) to be expressed as a function of just two variables. This works for expressing drag in the hump range because R/W is predominantly a function of trim. It does not work at different speed ranges where friction is a significant portion of R/W.

Analysis and derivation has also been done defining C_n as:

$$C_n = \nabla / (LCG^{3/2} B_m{}^{1/2}) \qquad (17)$$

And the buoyancy term as:

$$\Delta_b = 1/2\, f_1 (S_{LCGB}\, LCG)^{5/2} B^{1/2} Tan(\tau)\, \delta \qquad (18)$$

This approach is based on the buoyancy term used by Savitsky [6]. If R/W is plotted using C_n as defined in equation (17) and A_n for a given C_n and A_n in the hump range, small B_m/LCG planing craft often tend to have greater hump drag than high B_m/LCG planing craft. The best fit of the data for the various series reviewed occurs when the denominator of C_n is in the range of $LCG^{3/2} B_m{}^{1/2}$ to $LCG^{9/4} B_m{}^{3/4}$ such that the sum of the exponents equal three (keeps it non-dimensional). With this change the significance of B_m/LCG is generally not significant.

The R/W for the Dutch Series 62 (25 degree) is plotted using A_n and different definitions of C_n in Figs. (13), (16) and (17). $LCG^{3/2} B_m{}^{1/2}$ in the denominator works best for this series as it gave the best fit and minimized the overlap between the bands. The trim and S_{LCGB} is plotted with this denominator in the same manner as R/W in Figs. (18) and (19). The fit is very good and the overlap is very minimal. It should be noted that the top end of the Dutch Series 62 barely reached into high speed planing regime.

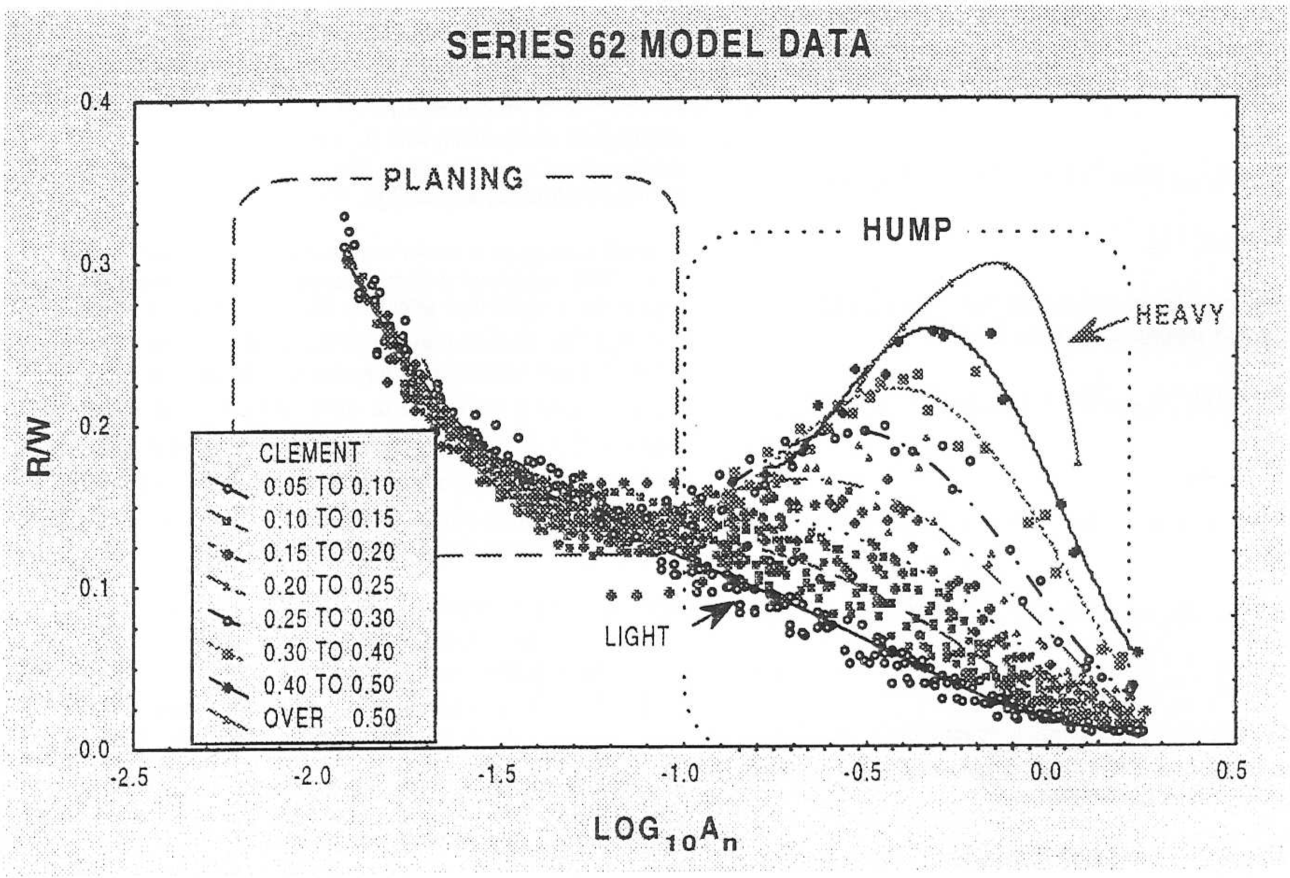

Fig. 10 Series 62 R/W Data Using Almeter Method

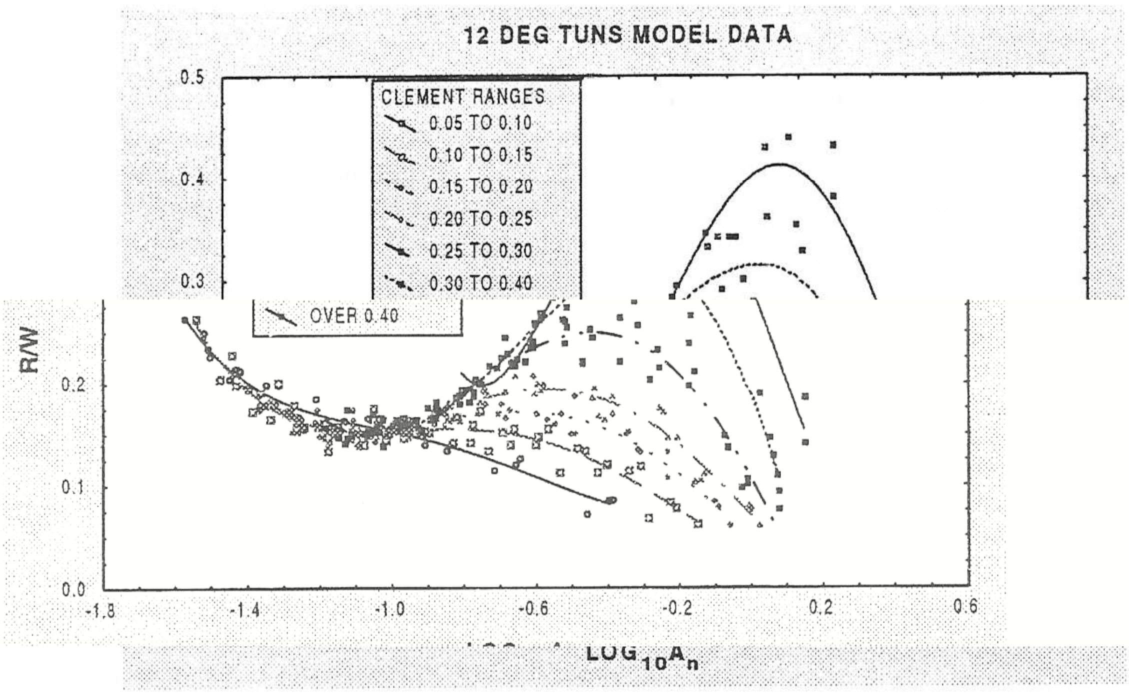

Fig. 11 TUNS 12-Degree Deadrise R/W Using Almeter Method

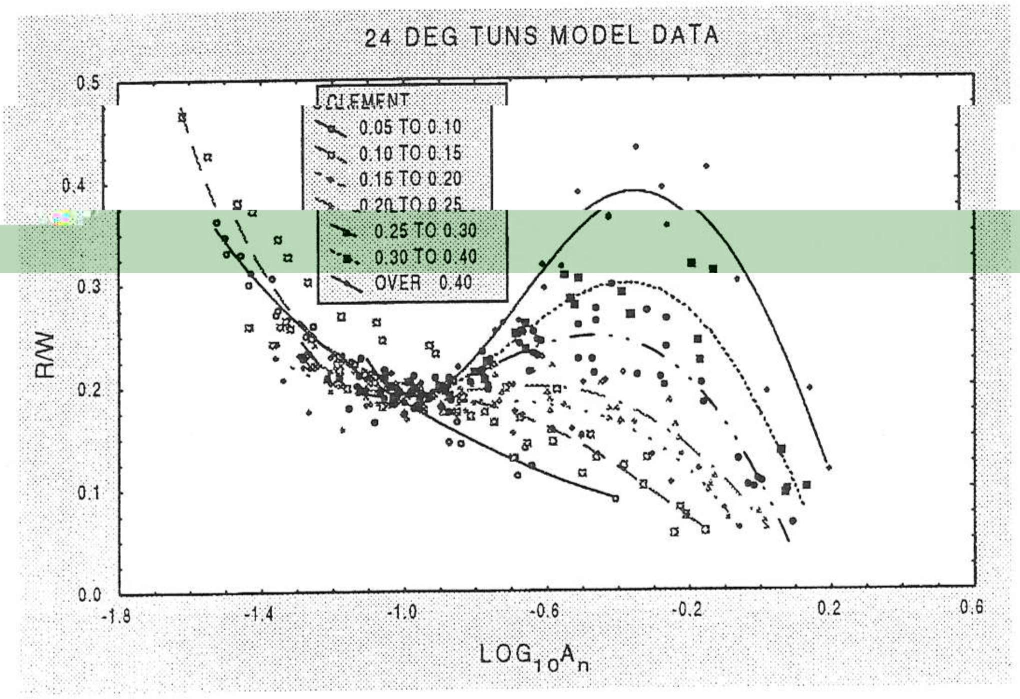

Fig. 12 TUNS 24-Degree Deadrise R/W Using Almeter Method

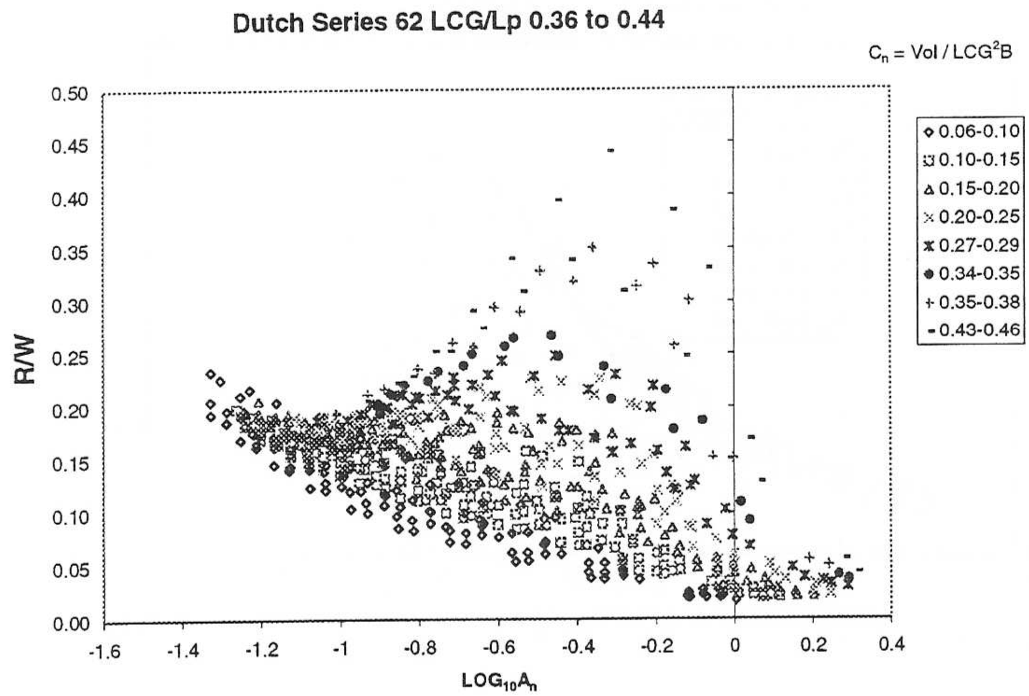

Fig. 13 Dutch Series 62 (25 Degree Deadrise) R/W Using Almeter Method

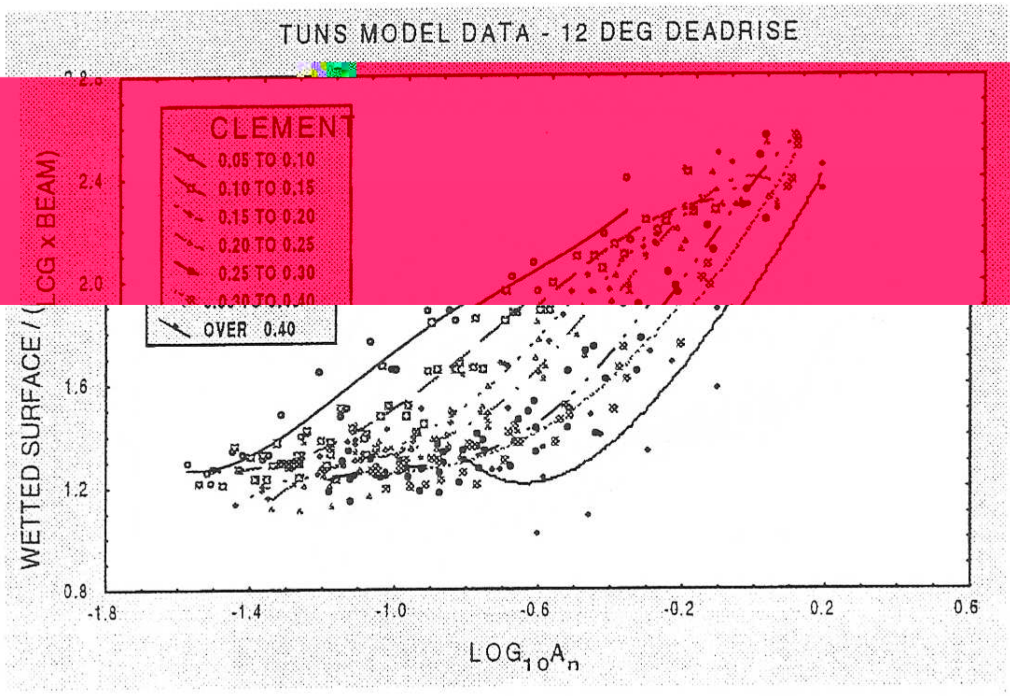

Fig. 14 TUNS 12 Degree Deadrise Trim Using Almeter Method

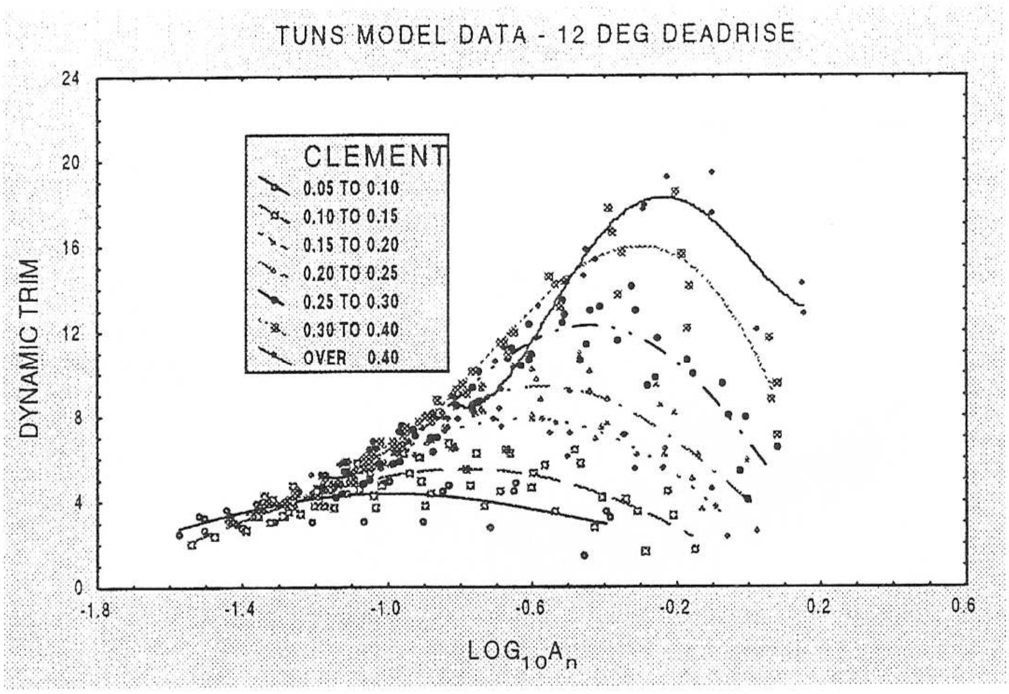

Fig. 15 TUNS 12 Degree Deadrise Wetted Surface Using Almeter Method

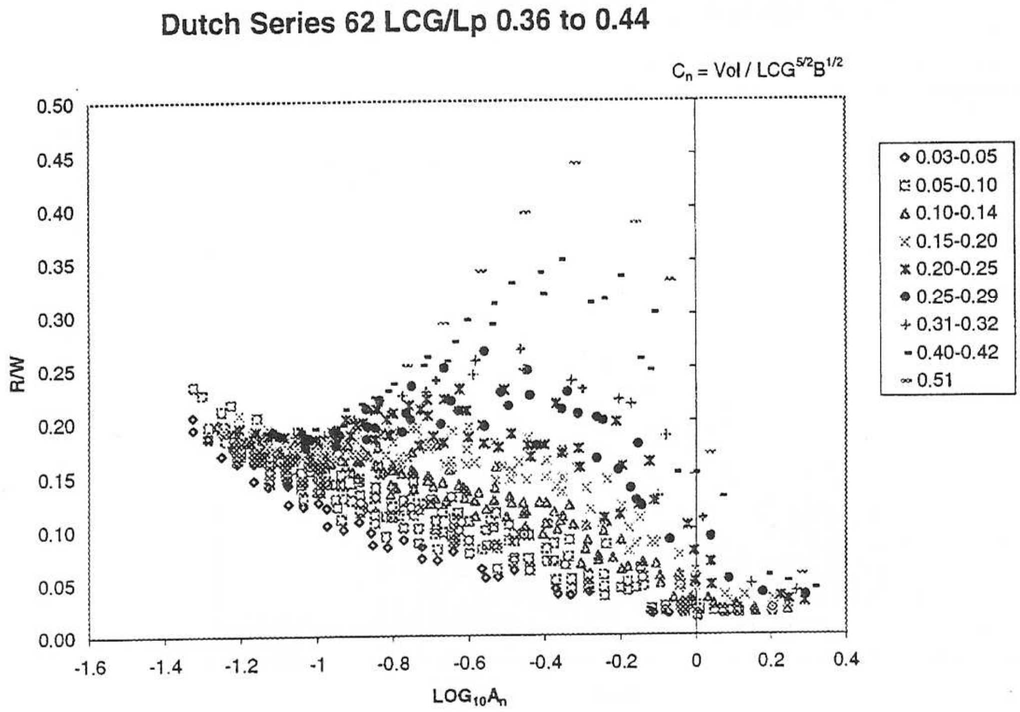

Fig. 16 Dutch Series 62 (25 Degree Deadrise) R/W With $C_n = \nabla / (LCG^{3/2} B_m^{1/2})$

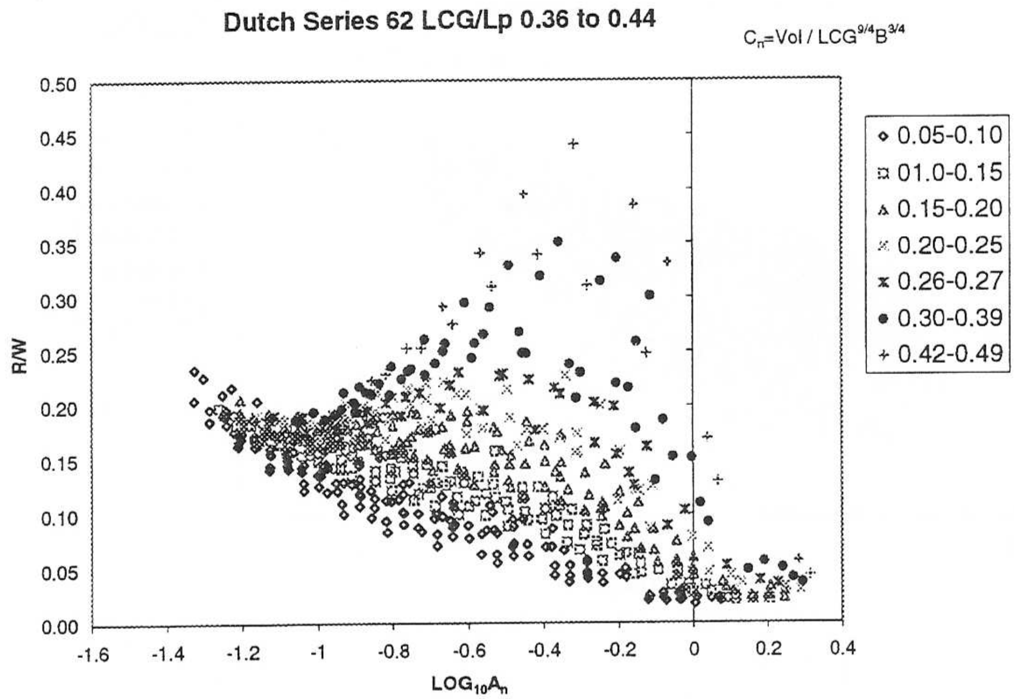

Fig. 17 Dutch Series 62 (25 Degree Deadrise) R/W With $C_n = \nabla / (LCG^{9/4} B_m^{3/4})$

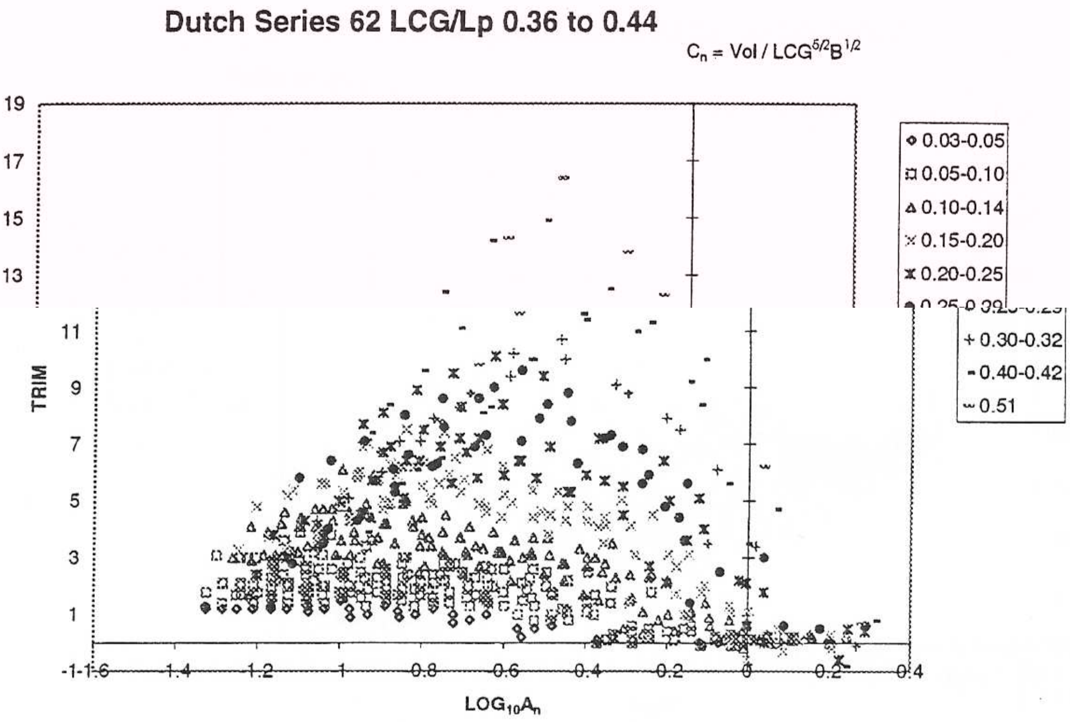

Fig.18 Dutch Series 62 (25 Degree Deadrise) Trim With $C_n = \nabla / (LCG^{5/2} B_m^{1/2})$

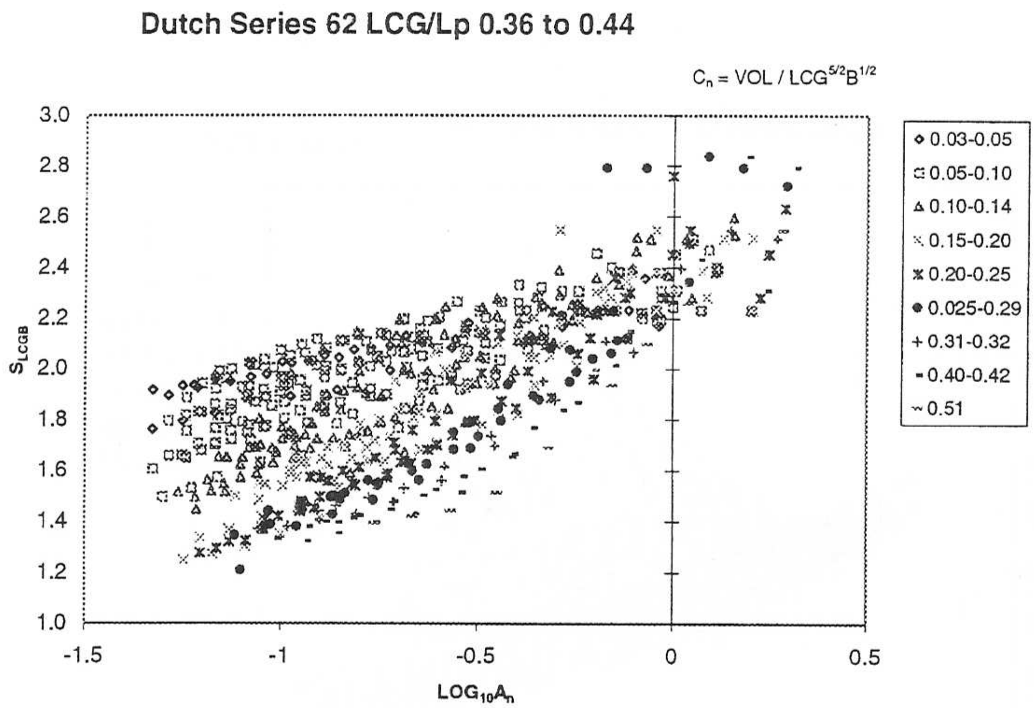

Fig. 19 Dutch Series 62 (25 Degree Deadrise) Wetted Surface With $C_n = \nabla / (LCG^{5/2} B_m^{1/2})$

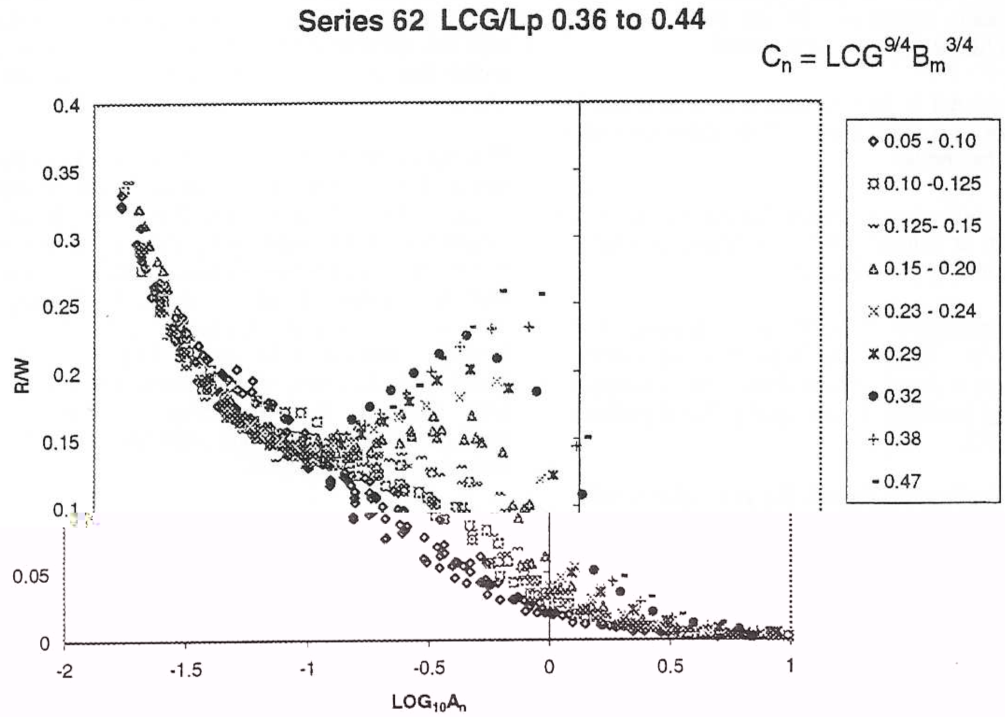

Fig. 20 Series 62 R/W With $C_n = \nabla / (LCG^{9/4} B_m^{3/4})$

Had the series been tested at higher speeds there would be greater convergence of trim and S_{LCGB}. The original American Series 62 is plotted in Fig. (20) for $LCG^{9/4}$ $B_m^{3/4}$. The fit with this denominator for C_n is very good.

3.6 APPLICABILITY TO ACTUAL PLANING CRAFT

The above discussions have been based largely on prismatic shapes of infinite length. In reality, boats are not prismatic and have finite length. The non-dimensional wetted surface cannot be greater than craft length divided by LCG. The non-prismatic bow of the craft is often wetted. This can become significant when there is an extremely large spread in LCG/L_p. Extreme far forward LCGs can result in excessive bow wetting and high resistance. This is not typical of most planing craft. The extreme forward test condition of the Series 62 is approximately $LCG/L_p = 0.48$. This extreme forward LCG of the Series 62 does not compress well as the aft and mid LCG locations using the method presented in this paper. The f_0 in equation (5) helps to address the differences between prismatic and actual planing craft. This approach works well for planing craft that are not true prismatic shapes as shown in the earlier figures. The relationships between S_{LCGB}, trim and R/Δ and A_n and C_n are very strong for typical planing craft.

The author has found that frictional scaling problems can be avoided if all of the data is scaled to the same nominal beam, 1-m, 5-m, etc. Corrections are not needed if there are only small differences in beams or if the emphasis is not in high speed planing. Almeter [10] provides a modified ATTC line that improves the frictional scaling of planing surfaces.

Spray and air drags do not scale perfectly with this approach. This is generally only a concern with extremely high speed planing craft. These problems can be avoided by subtracting out the spray and air drag from the data and then adding them separately to the prediction. Almeter [10] can be used for the prediction of spray drag. The L/B and LCG/L_p ratios may become more significant variables when the craft has features such as extreme hull warp (10 degrees) between midship and transom deadrise. However, even in these cases small differences in L/B and LCG/L_p ratios can be neglected. Hull warp tends to have the greatest effect at high planing speeds.

The beam of high speed planing hulls may not be fully wetted. The stagnation line may not reach all the way to the chine at the transom or there may be separation at a spray rail. The Almeter Method still works in these cases *if* the fully wetted beam is known and used.

The manner in which a model or full size craft is propelled can make a substantial difference in its resistance. The location and angle of the assumed "thrust line" can create substantial lift and moment on a planing hull. This is why many small planing boats have trim-able drives. Resistance data of the same hull at the same loading can be significantly different with different thrust lines. As discussed in great detail in Hubble [11] there are three basic ways a planing model can be towed in a model basin:

Type A - The model is free to heave and trim and is pulled in the thrust line. In this approach the towing carriage can create significant lift on the model for models with high hump drag at hump speed.

Type B - The model is free to heave and trim but is pulled horizontally at a fixed point. This approach does not create lift on the model.

Type C - The model is free to heave but not to trim. It is pulled horizontally at a fixed point. Trimming moments have to be measured in this method.

Type A is often considered to be more representative of actual craft behavior. Type B and Type C results can be "corrected" to Type A data by correcting for the presence or lack of towing carriage forces using the equations given in Hubble [11].

The Series 62 Planing Hull Series [4] has substantially lower hump drag for the heavily loaded models than the TUNS models [7]. This can be seen by comparing Figs. (10) and (11). Some of the substantial differences may be due to differences in the hulls and differences in chine beam taper. The primary reason for the differences is probably due to the Series 62 being tested using Type A methods and the TUNS model being tested using Type B methods. The weight of the Series 62 heavily loaded models at hump speed was partially supported by the towing carriage. This effectively reduced the loading on the model, reduced its trim and reduced its resistance with respect to the corresponding TUNS model that was pulled horizontally. Propulsors, waterjets and propellers, can have a substantial vertical thrust component (lift). The actual thrust line may not coincide with the assumed thrust line. This is one of the reasons that thrust deduction factors can be so important in powering prediction.

Great care is required to ensure that the resistance prediction method or data used either has a similar "assumed" thrust line or that the differences in the thrust lines are accounted for. This can be done by adding or deleting moments and forces as done in Hubble [11], Almeter [2], and Hoyt [12].

Moment adjustments or allowances may have to be made when predicting the resistance of planing craft where the ratio of the full size craft to model is large and skin friction dominates. This is discussed in detail in Hoyt [12].

3.7 APPLICATION OF THE ALMETER METHOD

A simple graph can be developed as shown in Fig. (5) based on the testing of one craft at three different loading conditions, Clement Numbers. The graph applies to craft with different L/B ratios, loadings, LCG locations, etc. The R/W of different Clement Numbers can be determined from interpolation. A regression or mathematical interpolation can be easily made because R/W is the function of only two variables, Almeter and Clement Numbers.

It is not uncommon to design a boat that is longer, heavier, etc. than an already existing "good" boat for which data is available. Predictions are often required for "off" conditions that do not correspond to the craft's normal load condition. The Almeter Method is often ideal for situations where there is minimal test data and the existing craft's loading or L/B ratio does not match that of the craft for which the prediction is being made.

This approach is very useful for comparing different hull forms. A hull form is often touted as having lower drag. A good method to validate the claim is to plot the resistance of the 'lower drag' boat against the drag of known hulls using the Almeter Method. The Almeter Method provides a valid tool for comparing hulls of different proportions, loadings, etc. The traditional Froude Method does not. This method and the information conveyed in this paper can aid the planing craft designer in determining the dimensions and proportions of planing hulls required to avoid excessive drag and hump problems.

4. CONCLUSIONS

Two dominant variables for the prediction of resistance of typical planing craft are the Almeter and Clement Numbers, A_n and C_n. The Almeter Method, using these variables, can be used to predict the resistance of similar craft from parents of different proportions and loadings. It provides a means to make good predictions using a very small amount of information as long as the limitations discussed in this paper are followed.

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