Planing Hull Resistance Calculation
The CAHI Method

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Panagiotis G. Alourdas
Naval Engineer

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Introduction

In recent years the operation of high speed planing craft for military, commercial and leisure use has increased. Speed and power calculation is a central theme of the design effort for high speed planing craft. The planing equations of the Savitsky method can be easily programmed and used by the high speed craft designer for the resistance prediction of planing hulls. The Savitsky method is probably the most commonly used method for the prediction of resistance of planing hulls. Blount and Fox (1976, Ref. 39) refer to it as the «predominant prediction method used within the small-craft technical community». The aim of this paper is to introduce the CAHI method into the high speed craft designer community. Both methods are valid for prismatic hulls. A prismatic hull has a constant cross section, therefore constant beam and constant deadrise, along the hull's entire length.

The Savitsky Method

The Savitsky method was first presented in 1964 (Savitsky 1964, Ref. 33). Since then the method was well documented in (Hadler 1966, Ref. 35), (Blount and Fox 1976, Ref. 39), (Savitsky and Brown 1976, Ref. 40) and (Doctors 1985, Ref. 42).

The method was interrogated for accuracy in (Clarke et al 1997, Ref. 53) and found satisfactory for design purposes.

Savitsky later developed a procedure for the calculation of the whisker spray resistance (Savitsky et al 2007, Ref. 57) and a procedure for estimating the resistance of warped planing hulls (Savitsky 2012, Ref. 69).

The Savitsky method was developed for application to non-monohedric hulls (Bertotello and Oliviero 2007, Ref. 58) and for application to stepped hulls (Svahn 2009, Ref. 63) and (Loni et al 2013, Ref. 74).

The Savitsky method was also used as a yardstick for comparison with CFD calculations of planing hull resistance (Caponnetto Ref. 59 & 60), (Brizzolara and Serra 2007, Ref. 61), (O’Shea et al 2012, Ref. 71) and (Fu et al 2012, Ref. 72).

The CAHI Method

The CAHI method is almost unknown to the high speed planing craft designer community. Almeter (1993, Ref. 51) made it known by comparing it with the Savitsky method but without giving the planing equations of the method. It should be noted that Almeter (1993, Ref. 51) was referring to the method as the Lyubomirov method.

In Peng Gongwu (2003, Ref. 80) and Zhang Qiao-bin et al (2012, Ref. 81) the method is referred to as the TSAGI (ЦАГИ) method from the initials (in Russian) of the Central Aero-Hydrodynamic Institute in Moscow.

The CAHI method is based on the dynamic lift equation of Sedov (1947, Ref. 8) and is similar to the Savitsky method with some differences. The lift coefficient, wetted length, and trim are calculated for a flat plate. The wetted length and trim are then corrected to allow for deadrise. In the CAHI method the wetted length (and surface) increases with deadrise. The planing equations of the CAHI method can also be easily programmed and used by the high speed craft designer for the resistance prediction of planing hulls.

It is worth noting that in Perelmuter (1938, Ref. 6), an initial form of the CAHI method can be found.

The Equations of the CAHI Method

In any method used for the calculation of the resistance of prismatic planing hulls, the known variables are the speed V, the hull weight Δ, the chine beam b, the deadrise angle β, and the longitudinal center of gravity LCG. The unknown variables are the mean wetted length over beam λ, and the trim τ.

The total hydrodynamic drag of a planing surface consists of two components, the pressure drag, which exists even in a frictionless and weightless fluid, and the friction drag. The total hydrodynamic drag D, is given by equation (20), the first term is the pressure drag and the second the friction drag. The pressure drag consists of the spray or splash drag, the induced drag and the wave drag (Wagner 1948, Ref. 10) and (Sedov 1965, Ref. 34).

The equations of the CAHI method can be found in Egorov et al (1978, Ref. 79). The principal equations of the method are the equations of the lift coefficient C_B (11) and of the moment of hydrodynamic forces m_Δ (12). Both equations are valid for a flat plate.

In the equation for the lift coefficient C_B (11), the first part is the hydrodynamic effect and the second the hydrostatic or buoyancy effect.

The hydrodynamic moment factor m_Δ, is defined by equation (7). In the absence of propulsor or thrust pitching moments the longitudinal center of gravity coincides reasonably with the longitudinal center of pressure, LCG = LCP and m_Δ, is defined by equation (8).

In order to determine the hydrodynamic characteristics of prismatic hulls, the equations (13) and (14) introduce corrections for the mean wetted length of the prismatic hull over beam λ_β, and the trim of the prismatic hull τ_β correspondingly.

As it is expected from theory, for a given condition of load and speed i.e. for the same lift coefficient, an increase in angle of deadrise will increase the wetted length and the trim and therefore the hydrodynamic resistance (Chambliss and Boyd 1953, Ref. 16).

Solving the Equations of the CAHI Method

First the equation (12) should be solved to find the mean wetted length over beam λ, and then using equation (11) the trim of the flat plate τ, could be calculated. In solving equation (12) as a first estimator for λ, the value of $(4/3)\cdot LCG$ can be used. The lift coefficient C_B is calculated from equation (3).

Having obtained the mean wetted length and the trim of the flat plate, the mean wetted length over beam of the deadrise planing surface λ_β, and the trim of the deadrise planing surface τ_β, could be calculated using the equations (13) and (14) respectively.

The wetted surface S, is calculated using equation (15), and the average bottom speed V_m, is calculated using equation (19). Finally the drag of the prismatic hull is calculated using equation (21). For the calculation of the friction coefficient C_F, the ITTC equation (22) or Schoenherr equation (23) can be used.

The wetted length at keel L_k, and the wetted length at chine L_c, are calculated using equations (17) and (18).

Comparisons with Experimental Results

Some comparisons were made with experimental results.

At first the data from the model tests of Shoemaker (1934, Ref. 4) were used.

The Model 29 (prismatic surface) with: $b = 16.0$ in, $\beta = 20$ deg. and $W = 80$ lbs, was used at two speeds.

$V = 18.01$ knots, LCG = 18.5 in, $C_V = 4.64$, $F_\nabla = 5.16$, $C_\Delta = 0.53$			
	SAVITSKY	**CAHI**	**MODEL TEST**
LAMDA	1.59	1.68	2.31
TRIM	4.21	3.95	4.0
D/W	0.19	0.19	0.19
DRAG (lbs)	15.12	15.17	15.20

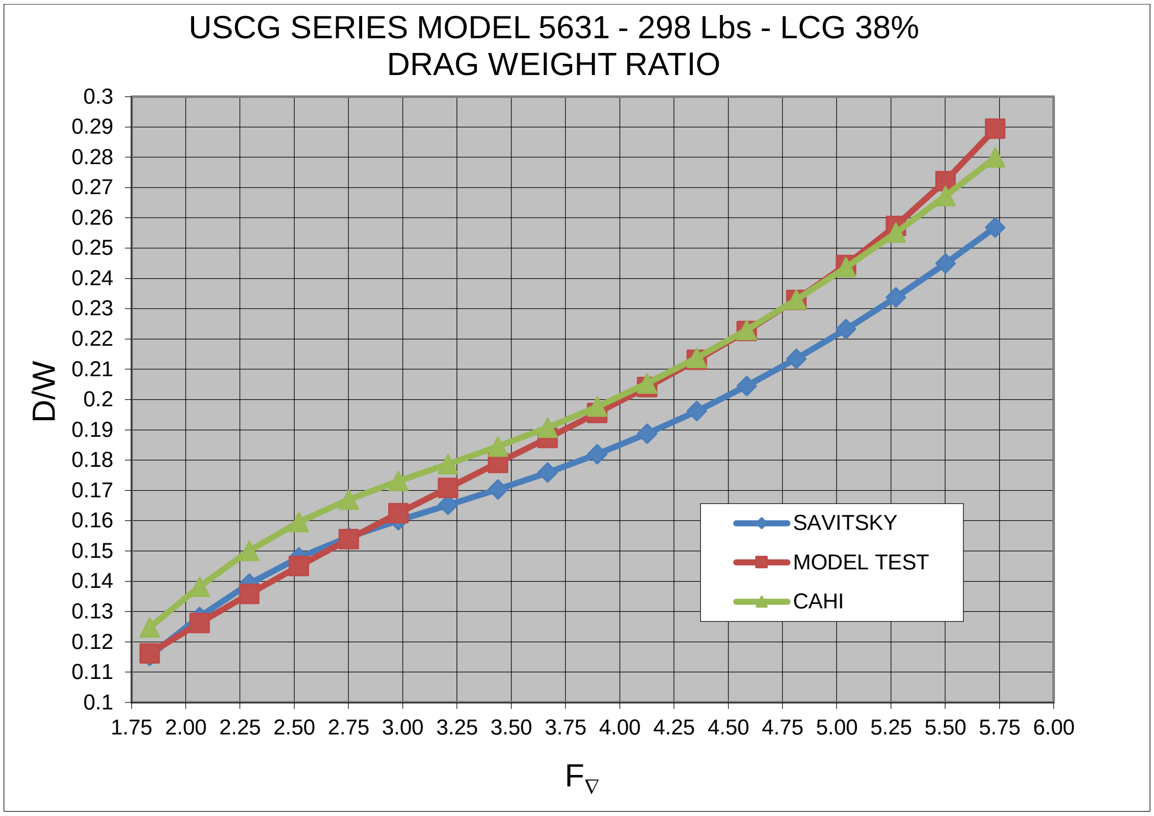
$V = 20.92$ knots, LCG = 18.3 in, $C_V = 5.39$, $F_\nabla = 5.99$, $C_\Delta = 0.53$			
	SAVITSKY	**CAHI**	**MODEL TEST**
LAMDA	1.56	1.62	1.81
TRIM	3.46	3.32	4.0
D/W	0.21	0.21	0.20
DRAG (lbs)	16.76	16.89	16.0

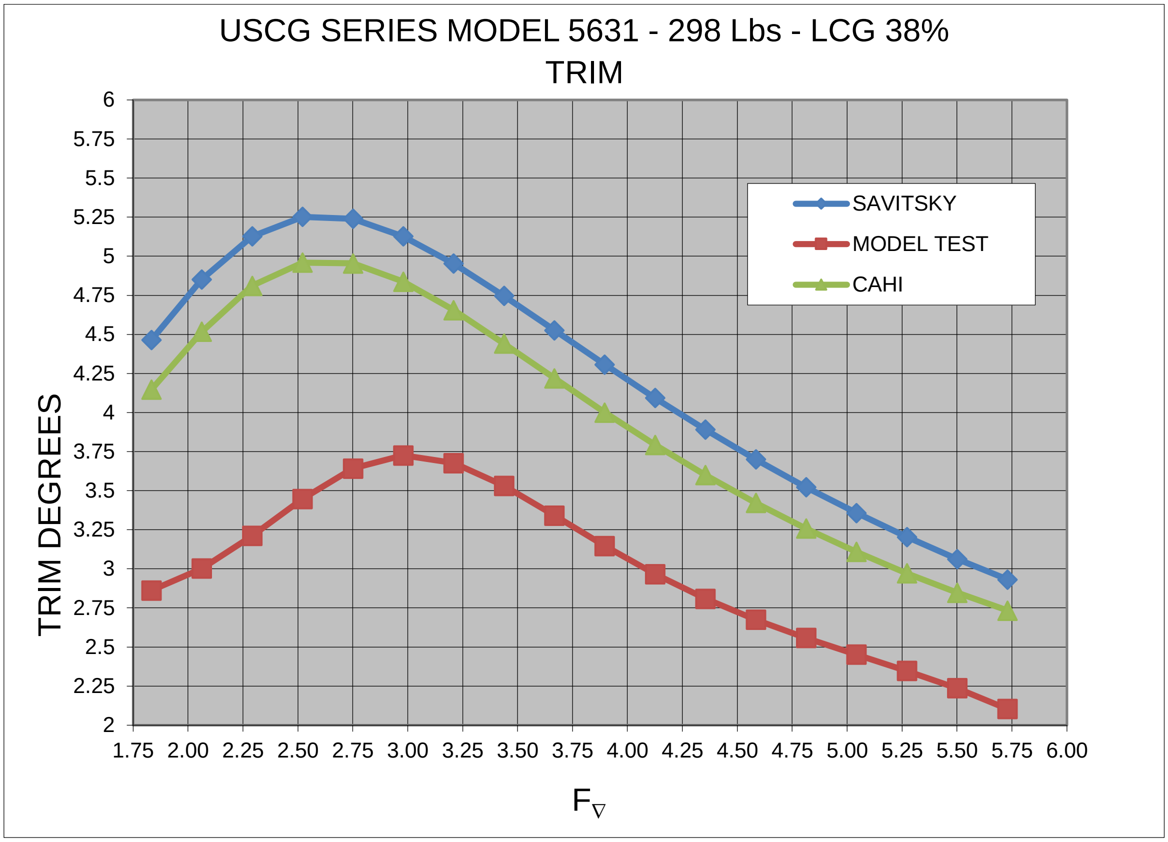
The experimental results of the systematic series of high speed planing crafts based on the US Coast Guard 47 ft MLB hull form (Metcalf et al 2005, Ref. 55) and (Kowalyshyn et al 2006, Ref. 56) were also used for comparison.

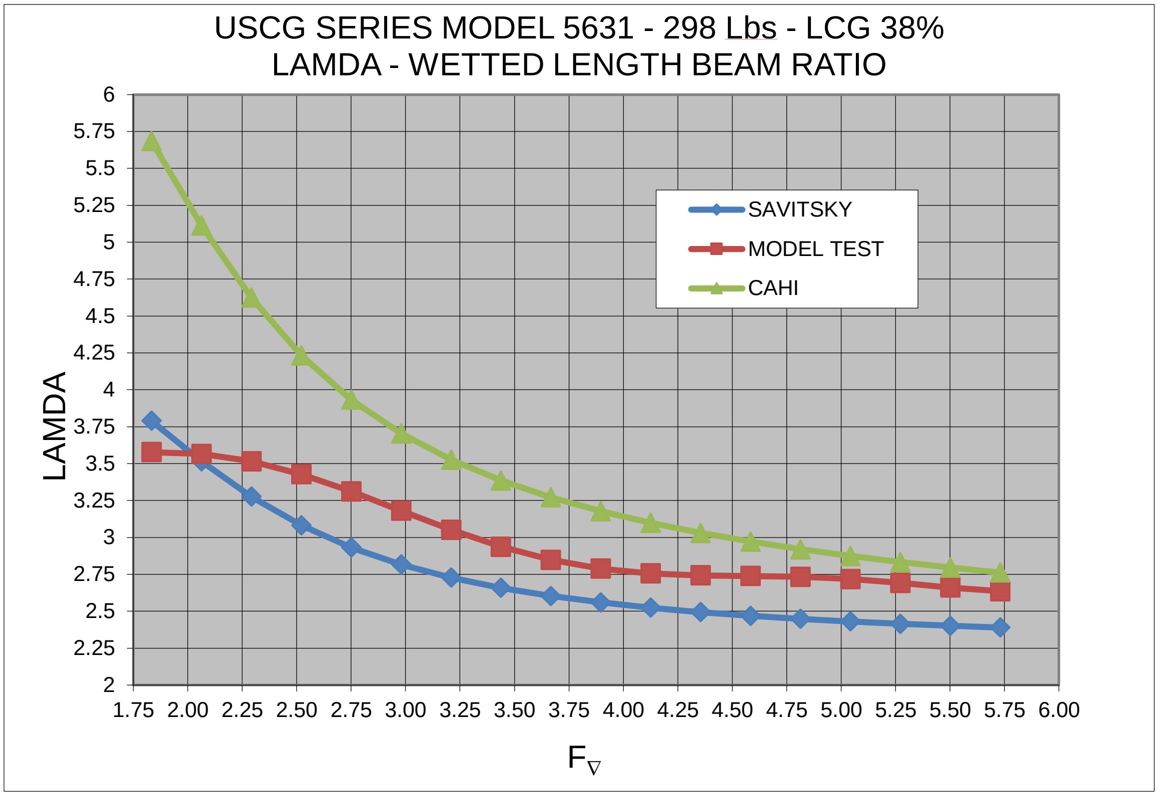
The Model 5631 with: $b = 2.24$ ft, $\beta = 20$ deg. and $W = 298$ lbs, was used at all speeds.

The results of the comparison show satisfactory agreement of both methods with the experimental data.

It should be noted that no conclusions could be drawn about the relevant accuracy of the methods, because as it was pointed by Almeter (1993, Ref. 51) the accuracy of the predictions depends on the different cases of load, deadrise and speed.


USCG SERIES MODEL 5631 - 298 Lbs - LCG 38%
DRAG WEIGHT RATIO
D/W
0.3
0.29
0.28
0.27
0.26
0.25
0.24
0.23
0.22
0.21
0.2
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
4.25
4.50
4.75
5.00
5.25
5.50
5.75
6.00
F∇
SAVITSKY
MODEL TEST
CAHI


USCG SERIES MODEL 5631 - 298 Lbs - LCG 38%
TRIM
TRIM DEGREES
6
5.75
5.5
5.25
5
4.75
4.5
4.25
4
3.75
3.5
3.25
3
2.75
2.5
2.25
2
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
4.25
4.50
4.75
5.00
5.25
5.50
5.75
6.00
F∇
SAVITSKY
MODEL TEST
CAHI


USCG SERIES MODEL 5631 - 298 Lbs - LCG 38%
LAMDA - WETTED LENGTH BEAM RATIO
LAMDA
6
5.75
5.5
5.25
5
4.75
4.5
4.25
4
3.75
3.5
3.25
3
2.75
2.5
2.25
2
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
4.25
4.50
4.75
5.00
5.25
5.50
5.75
6.00
F_∇
SAVITSKY
MODEL TEST
CAHI

Nomenclature

V = speed, m/s
V_m = average bottom speed, m/s
ρ = mass density of water, kg/m^3
g = acceleration due to gravity, m/s^2
Δ = load on the planing surface (craft weight), N
W = craft weight, N
($\Delta = W$)
∇ = displacement volume of craft, m^3
b = chine beam, m
β = deadrise angle, radians
LCG = longitudinal center of gravity, m
(LCG measured from trailing edge, i.e. transom or step)
C_F = coefficient of friction
C_B = lift coefficient (dynamic load factor)
C_Δ = static load factor
C_V = Froude number based on beam, speed coefficient
D = drag, N
F_∇ = Froude number based on volume
ℓ = wetted length of flat plate, m
L_m = mean wetted length of deadrise planing surface, m
L_k = wetted length of deadrise planing surface at keel, m
L_c = wetted length of deadrise planing surface at chine, m
LCP = longitudinal center of pressure, m
(LCP measured from trailing edge, i.e. transom or step)
LCG ≈ LCP in the absence of propulsor or thrust pitching moments
m_Δ = hydrodynamic moment factor
M = moment of the hydrodynamic forces, Nm
(with respect to the trailing edge of the plate/hull, i.e. transom or step)
R_n = Reynolds number based on the mean wetted length of the deadrise planing surface
S = wetted surface, m^2
λ = mean wetted length of flat plate over beam
λ_β = mean wetted length of deadrise planing surface over beam
τ = trim of flat plate, radians
τ_β = trim of deadrise planing surface, radians

Equations

$$C_V = \frac{V}{\sqrt{gb}} \tag{1}$$

$$F_\nabla = \frac{V}{\sqrt{g\nabla^{1/3}}} \tag{2}$$

$$C_B = \frac{\Delta}{0.5\rho V^2 b^2} \tag{3}$$

$$C_\Delta = \frac{\Delta}{\rho g b^3} \tag{4}$$

$$C_V = F_\nabla C_\Delta^{1/6} \tag{5}$$

$$C_B = \frac{2C_\Delta}{C_V^2} \tag{6}$$

$$m_\Delta = M/\Delta b \tag{7}$$

$$m_\Delta = LCG/b \tag{8}$$

$$LCG = LCP \tag{9}$$

$$\lambda = \ell/b \tag{10}$$

$$C_B/\tau = \frac{0.7\pi\lambda}{1+1.4\lambda} + \frac{\lambda-0.4}{\lambda+0.4}\cdot\frac{\lambda^2}{C_V^2} \tag{11}$$

$$m_{\Delta}=\frac{\frac{0.7\pi\lambda}{1+1.4\lambda}\cdot\left(0.75+0.08\frac{\lambda^{0.865}}{\sqrt{C_V}}\right)+\frac{\lambda\text{-}0.8}{3\lambda+1.2}\cdot\frac{\lambda^2}{C_V{}^2}}{\frac{0.7\pi}{1+1.4\lambda}+\frac{\lambda-0.4}{\lambda+0.4}\cdot\frac{\lambda}{C_V{}^2}} \tag{12}$$

$$\lambda_{\beta}=\frac{\lambda^{0.8}}{\cos\beta}\left[1-0.29(\sin\beta)^{0.28}\right]\cdot\left[1+1.35(\sin\beta)^{0.44}\cdot\frac{m_{\Delta}}{\sqrt{C_V}}\right] \tag{13}$$

$$\tau_{\beta}=\tau+\frac{0.15(\sin\beta)^{0.8}}{C_V{}^{0.3}}\cdot\frac{1-0.17\sqrt{\lambda_{\beta}\cos\beta}}{\sqrt{\lambda_{\beta}\cos\beta}} \tag{14}$$

$$S=\frac{b^2\,\lambda_{\beta}}{\cos\beta} \tag{15}$$

$$\lambda_{\beta}=L_m/b \tag{16}$$

$$L_m=\frac{L_k+L_c}{2} \tag{17}$$

$$L_k-L_c=\frac{b\tan\beta}{\pi\tan\tau} \tag{18}$$

$$V_m=V\left(1-\frac{\tau}{1+\lambda}\right) \tag{19}$$

$$D = \Delta \tan \tau_\beta + \frac{D_F}{\cos \tau_\beta} \tag{20}$$

$$D = \Delta \tan \tau_\beta + \frac{0.5 C_F \rho S V_m^{\ 2}}{\cos \tau_\beta} \tag{21}$$

$$C_F = \frac{0.075}{(\log R_n - 2.0)^2} \tag{22}$$

$$\frac{0.242}{\sqrt{C_F}} = \log(R_n C_F) \tag{23}$$

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