The Resistance of the Delft 372 Hull

Abstract. The towing tank results of the Delft 372 hull are widely used for the validation of CFD predictions for the wave resistance of ships. This report lists numerical values for the resistance of the monohull, extracted from published diagrams and discusses possible corrections, necessary to determine the residual resistance from the measurements.

NOMENCLATURE

A_{wet}	Wetted area of canoe body
Fn	Froude number $U / (g \cdot L_{WL})^{1/2}$
g	gravitational acceleration = 9.81 m/s^2
L_{WL}	Length of the water line at rest
R	Resistance force
Re	Reynolds number $U \cdot L_{WL} / \nu$
Tu	Turbulence level
U	Ship speed
u',v',w'	Fluctuating velocities
ρ	Density of the water
ν	Kinematic viscosity of the water

1. INTRODUCTION

The Delft-372 catamaran has been the object of extensive investigations. A large database of towing tank experiments and numerical simulations exists in the literature [1]-[4]. For validation work it is desirable to have a table with numerical values at hand. Resistance values are published in the open literature only in the form of diagrams. These diagrams were therefore scanned and digitized. The digitized lines plan was used to model the hull as a 3-D surface in a CAD-program. From this 3-D model all necessary input files for numerical simulations e.g. offset-files can be generated. The lines plan created from the 3-D model is depicted in figure 1.

2. THE VISCOUS RESISTANCE

The resistance values published in [2] were determined with the INSEAN-2554 model that employs a boundary layer trip consisting of a row of cylindrical pins. The results were reported once in 2011 [2] and once in 2014 [3]. The results are identical with the exception of the value at Fn = 0.1. In 2011 the measured resistance was 10% higher than in 2014. This is an indication, that the b.l.-trip might not be sufficient at low speeds to force the b.l. into the turbulent state. The effect of the b.l.-trip depends heavily on the turbulence level in the towing tank [5] and Tu in turn is very sensitive to the waiting time between consecutive test runs in the tank, especially at low speeds. The towed model creates a vortex-street in its wake and this vorticity decays very slowly over time. The rotating eddies lead to fluctuations of the velocity in the b.l. of the model in the following test-run. Since Tu is defined as:

$$Tu = \frac{\sqrt{\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right) / 3}}{U} \tag{1}$$

a small denominator i.e. low speeds causes a high Tu and therefore a high sensitivity to the vorticity in the tank. This might be the explanation for the varying values at Fn = 0.1. For validation purposes it is necessary to apply Froude's method and to split the total measured resistance into a viscous and a wave-making part. The viscous resistance is computed here with an integral method for the boundary layer calculation as described in [5]. The viscous resistance coefficient is defined as:

$$C_{visc} = \frac{R_{visc}}{\frac{1}{2} \cdot \rho \cdot U^2 \cdot A_{wet}} \tag{2}$$

The result is the green line in figure 2. It is shown together with a prediction that uses Grigson's friction line and a form factor [6] to calculate the resistance coefficient. The agreement for fully developed turbulent flow is quite good. At low speeds below Fn = 0.3 the viscous drag follows a friction line that runs below the one for turbulent flow. At these low speeds the b.l.-trip can not trigger the transition from laminar to turbulent flow and the flow remains laminar along the forward part of the hull until natural transition occurs. This extended laminar flow results in a lower viscous drag.

Broglia et al. [2] compare their results with other measurements in the literature and conclude that their measured resistance is slightly too high. They identify the drag of the pins as the root cause and propose to use corrected resistance values. Adding the drag of the estimated 16 pins to the viscous resistance from the b.l.-calculation yields the blue line in figure 2. The reduced dynamic pressure in the b.l. was taken into account when calculating the pin drag [7].

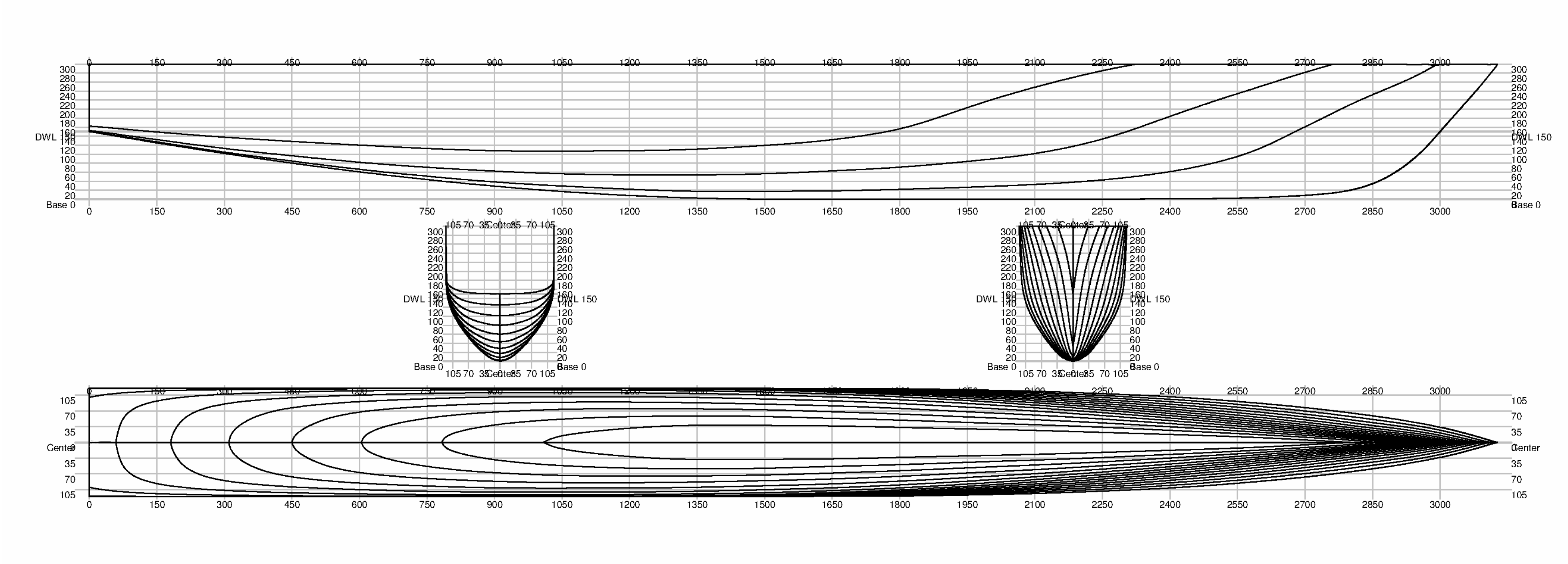

Figure 1. Lines plan Delft-372 monohull

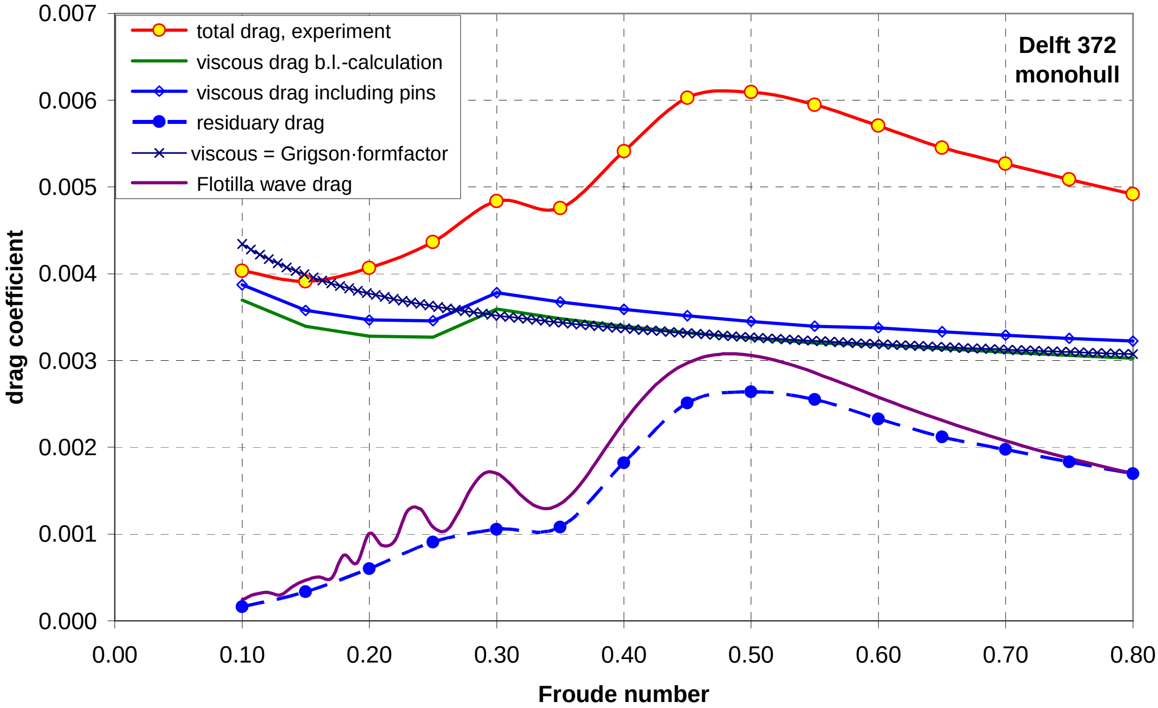

Figure 2. Resistance coefficients for the monohull Delft-372

3. THE RESIDUARY RESISTANCE

The difference between the measured total resistance and the viscous resistance (including pin drag) is the residuary resistance. The result is shown in figure 2. Numerical values are listed in table 1 at the end of this paper as a database for validation purposes.

4. COMPARISON WITH FLOTILLA

With a length to beam ratio of 12.5 it should be possible to use Michell's thin ship theory for the prediction of the wave resistance. The curve in figure 2 was calculated with the program Flotilla [6]. The prediction is qualitatively quite good, the humps and hollows are at the right Froude numbers, but the absolute values are too high. The half entrance angle of the hull Delft-372 is 7 degrees, which is small enough for the application of the thin ship theory. The root cause of the difference is most likely the large radius of the waterlines at the rear end. Very high speeds are needed until the produced wave length becomes large compared to this radius. In the photographs in [3] it is visible that the transom is dry and clearly above the water surface for $Fn > 0.35$. The position of the transom has therefore most likely no significant effect on the wave resistance.

5. REFERENCES

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6. APPENDIX

Fn	*Re*	$C_{residuary}$	$C_{viscous}$
0.10	1.426E+06	0.00016	0.00370
0.15	2.139E+06	0.00033	0.00340
0.20	2.852E+06	0.00060	0.00328
0.25	3.565E+06	0.00091	0.00327
0.30	4.278E+06	0.00105	0.00359
0.35	4.991E+06	0.00108	0.00348
0.40	5.704E+06	0.00182	0.00340
0.45	6.417E+06	0.00251	0.00332
0.50	7.130E+06	0.00264	0.00326
0.55	7.843E+06	0.00255	0.00320
0.60	8.556E+06	0.00233	0.00318
0.65	9.269E+06	0.00212	0.00314
0.70	9.982E+06	0.00197	0.00310
0.75	1.069E+07	0.00183	0.00306
0.80	1.141E+07	0.00170	0.00303

Table1. Resistance values for Delft-372 viscous resistance without pin drag