A Systematic Ferry Series

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Abstract. A number of seventeen models of Ferry in scale 1: 28.750 of 10250 ton displacement have been built at the Italian Model Basin, to be tested in the Emilio Castagneto towing tank at INM in Rome. The results of the tests have been collected in this report, delivered and presented in easy and useful form.

Keywords. Systematic series, Big data, resistance tests

1. Introduction

A number of seventeen models of Ferry in scale 1: 28.750 of 10 250.0 tons displacement have been built at the Italian Model Basin, to be tested in Rome. The results of the tests have been collected in this report, delivered and presented in easy and useful form. The hull C.2054 has been used to build the whole Series, the variations in the forms have been obtained maintaining the same displacement, operating the deformation of the hull in the x, y, z directions using the following parameters:

p = L derived hull / L generating hull
q = B derived hull / B generating hull
r = T derived hull / T generating hull

The derived hulls have all constant volume, while the product p · q · r = 1

The naked hulls have been tested in this conditions:

Δ = 10 250.0 t corresponding to 10 000 m^3, project condition, straight trim, CB = 0.515, CM = 0.943, CP = 0.546, CW = 0.715, CVP =0.720, LCB = -1.71% , XCF = - 5.33%.

Figure 1. The generating hull model 2054 during the tests

For the symbols used, refer to the ITTC symbology [11]

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2. The Models

The seventeen models have been built in wood, tested in the Emilio Castagneto towing tank at INM in Rome, 220 meters long, 9 meters wide, 3.5 meters deep. They all have been fitted with turbulence stimulators, nails of 2.5 mm diameter and 2 mm overhang, following the ITTC recommendations. The models have the following dimensions, as shown in Table 1.

Table 1. The 17 models of the Systematic Ferry Series

Hull	L	B	T	p	q	r	ie /2	$S / V^{2/3}$
	m	m	m	-	-	-	degree	-
2052	3.7411	0.8797	0.2484	1 / 1.3	√1.3	√1.3	16.78	5.918
2053	4.2655	0.8239	0.2325	1/√1.3	$\sqrt[4]{1.3}$	$\sqrt[4]{1.3}$	13.91	6.256
2054	4.8634	0.7716	0.2177	1	1	1	11.50	6.657
2055	6.3224	0.6767	0.1909	1.3	1/√1.3	1/√1.3	7.82	7.623
2056	4.8634	0.5935	0.2830	1	1/1.3	1.3	8.89	6.657
2057	4.8634	0.8797	0.1909	1	√1.3	1/√1.3	12.5	6.924
2058	4.8634	1.0030	0.1675	1	1.3	1/1.3	14.81	7.356
2159	4.8634	0.6767	0.2484	1	1/√1.3	√1.3	9.80	6.648
2160	6.3224	0.7716	0.1675	1.3	1	1/1.3	8.89	7.907
2161	6.3224	0.5935	0.2177	1.3	1/1.3	1	7.10	7.522
2162	5.5451	0.8797	0.1675	√1.3	√1.3	1/1.3	11.50	7.634
2163	5.5451	0.5935	0.2484	√1.3	1/1.3	√1.3	7.82	7.084
2164	5.5451	0.7226	0.2039	√1.3	$1/\sqrt[4]{1.3}$	$1/\sqrt[4]{1.3}$	9.49	7.168
2165	3.7411	1.0030	0.1909	1/√1.3	1.3	1/√1.3	16.78	6.628
2166	3.7411	0.6767	0.2830	1/√1.3	1/√1.3	1.3	11.50	6.377
2167	3.2812	1.0030	0.2177	1/1.3	1.3	1	18.97	6.153
2168	3.2812	0.7716	0.2830	1/1.3	1	1.3	14.81	5.868

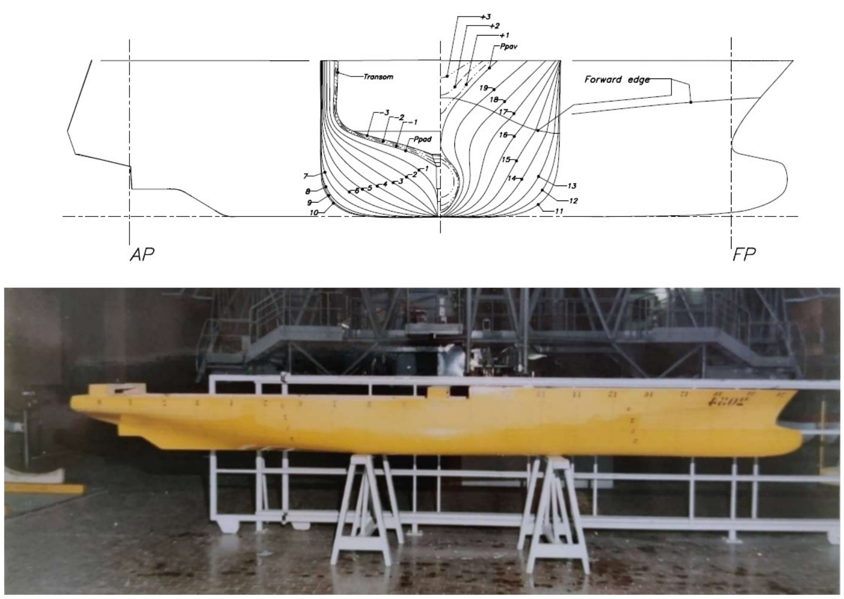

Figure 2. The generating forms of the Serie Models and hull model 2054

3. The wetted surface

The wetted surface and the entrance angle are free of any variation, while the L/B ratio depends on the block coefficient, the $L/V^{1/3}$ and B/T coefficients, with $L/B = [\, C_B \cdot L^3/V \cdot T/B \,]^{1/2}$. The wetted surface has been measured for all the hulls; with these value has been obtained a 2nd degree polynomial surface fitting, where the $S/V^{2/3}$ surface is function of $L/V^{1/3}$ and B/T, independent variables:

$$S/V^{2/3} = 4.246+0.5085 \cdot L/V^{1/3}-0.5757 \cdot B/T-0.009741 \cdot (L/V^{1/3})^2+ \\ +0.03287 \cdot L/V^{1/3} \cdot B/T+0.06757 \cdot (B/T)^2 \qquad (1)$$

Table 2. The 17 models of the Systematic Series T90, dimension-less form coefficients:

Hull	$L/V^{1/3}$	$B/V^{1/3}$	$T/V^{1/3}$	L/B	B/T	$S/V^{2/3}$ measured	$S/V^{2/3}$ fitted
2052	4.994	0.8797	0.331	4.254	3.544	5.918	5.933
2053	5.694	0.8239	0.310	5.179	3.544	6.256	6.298
2054	6.493	0.7716	0.291	6.307	3.544	6.657	6.702
2055	8.440	0.6767	0.255	9.347	3.544	7.623	7.636
2056	6.493	0.5935	0.378	8.198	2.097	6.657	6.675
2057	6.493	0.8797	0.255	5.531	4.607	6.924	6.903
2058	6.493	1.0030	0.223	4.851	5.989	7.356	7.392
2159	6.493	0.6767	0.335	7.190	2.694	6.648	6.652
2160	8.440	0.7716	0.223	8.198	4.607	7.907	7.905
2161	8.439	0.5935	0.291	10.656	2.726	7.522	7.533
2162	7.403	0.8797	0.223	6.306	5.253	7.634	7.596
2163	7.403	0.5935	0.331	9.347	2.391	7.084	7.069
2164	7.403	0.7226	0.272	7.678	3.544	7.168	7.148
2165	5.695	1.0030	0.255	4.255	5.253	6.628	6.650
2166	5.695	0.6767	0.378	6.308	2.390	6.377	6.284
2167	4.994	1.0030	0.291	3.731	4.607	6.153	6.081
2168	4.994	0.7716	0.378	4.851	2.726	5.868	5.923

The models are so represented in the $L/V^{1/3}$ and B/T plane:

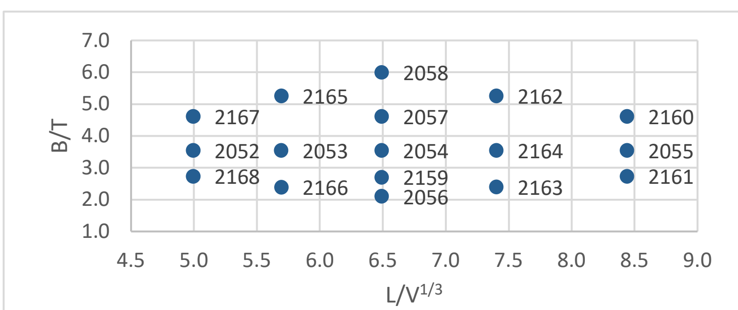

Figure 3. The 17 models in the $L/V^{1/3}$ B/T plane

4. How to present the results

The results of the systematic Series will be useful to predict the total resistance of the hulls to be designed, regardless of their actual size.

Classical way is to add the frictional resistance to the residual resistance, using the systematic Serie to predict the residual part of the resistance, while the frictional part is calculated with the well-known frictional coefficient - C_f - once we know the length, the wetted surface, the volume and the speed.

4.1. Residual Resistance Prediction

The resistance towing tests, performed with the seventeen models, give us the residual resistance coefficient as function of the Froude number, CR=f (FR) .We collected these results in 5th degree polynomial equations, to interpolate the CR for any desired speed. The polynomial equations are here shown in Table 3:

Table 3. The residual resistance coefficient $CR \cdot 10^3$ as function of Froude number

Hull	$L/V^{1/3}$	B/T	
C.2052	4.99	3.54	$CR = 29496FR^5 - 26789FR^4 + 9299.1FR^3 - 1521.7FR^2 + 118.77FR - 2.9579$
C.2053	5.69	3.54	$CR = 28306FR^5 - 26518FR^4 + 9494.3FR^3 - 1600.2FR^2 + 127.17FR - 3.2867$
C.2054	6.49	3.54	$CR = 4218.1FR^5 - 2769.4FR^4 + 609.01FR^3 - 47.386FR^2 + 2.7577FR + 0.1188$
C.2055	8.44	3.54	$CR = 999.83FR^5 - 650.21FR^4 + 154.84FR^3 - 13.473FR^2 + 0.8152FR + 0.2165$
C.2056	6.49	2.10	$CR = 23968FR^5 - 22193FR^4 + 7707.1FR^3 - 1228.5FR^2 + 89.97FR - 2.3594$
C.2057	6.49	4.61	$CR = 8469.2FR^5 - 6891.6FR^4 + 2129.4FR^3 - 305.5FR^2 + 21.566FR - 0.1474$
C.2058	6.49	5.99	$CR = 1912.8FR^5 - 224.22FR^4 - 462.91FR^3 + 164.61FR^2 - 13.998FR + 0.3215$
C.2159	6.49	2.69	$CR = 10975FR^5 - 9354FR^4 + 2980.8FR^3 - 421.92FR^2 + 24.422FR + 0.069$
C.2160	8.44	4.61	$CR = 5081FR^5 - 4623.8FR^4 + 1602.7FR^3 - 255.87FR^2 + 19.185FR - 0.2217$
C.2161	8.44	2.73	$CR = 2609.3FR^5 - 1770.7FR^4 + 395.77FR^3 - 28.163FR^2 + 0.6118FR + 0.2363$
C.2162	7.40	5.25	$CR = 1154.3FR^5 - 897.75FR^4 + 380.14FR^3 - 88.477FR^2 + 10.131FR + 0.1741$
C.2163	7.40	2.39	$CR = 146.1FR^5 + 920.37FR^4 - 729.52FR^3 + 210.16FR^2 - 26.256FR + 1.5747$
C.2164	7.40	3.54	$CR = 9064.6FR^5 - 7507.4FR^4 + 2331.4FR^3 - 330.58FR^2 + 21.756FR - 0.2028$
C.2165	5.69	5.25	$CR = 11373FR^5 - 8915.1FR^4 + 2575.8FR^3 - 332.2FR^2 + 21.328FR + 0.0271$
C.2166	5.69	2.39	$CR = 20960FR^5 - 19246FR^4 + 6734.4FR^3 - 1104.7FR^2 + 84.561FR - 2.0084$
C.2167	4.99	4.61	$CR = 22364FR^5 - 19507FR^4 + 6506.5FR^3 - 1028.9FR^2 + 81.343FR - 2.1136$
C.2168	4.99	2.73	$CR = 29981FR^5 - 28097FR^4 + 10208FR^3 - 1776.8FR^2 + 147.72FR - 3.950$

The global results of CR=f (FR) for the whole Series of models is obtained with a 3^{rd} degree polynomial surface fitting, where the CR surface, for any FR, is function of $L/V^{1/3}$ and B/T.

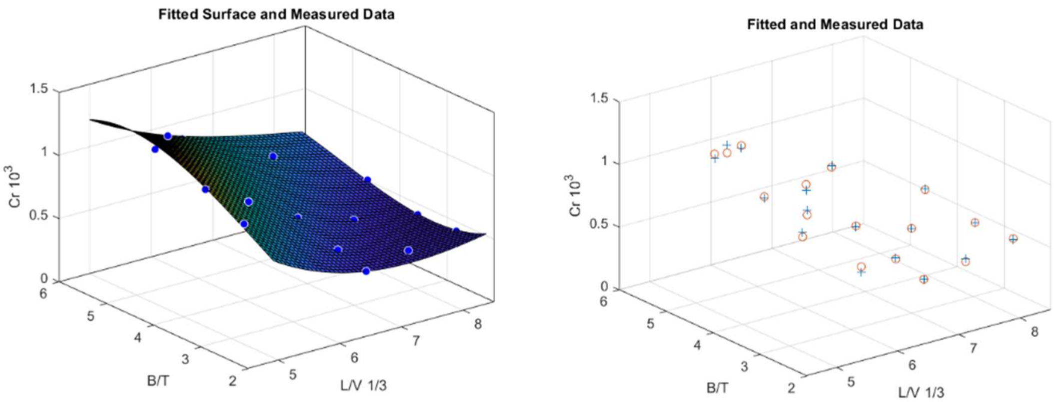

Figure 4. Fitted Surface (left) and Fitted Data (right) together with Measured Data at Froude number 0.250

The fit will assume this form, and the surface can be drawn in iso level curves, at constant Froude number, in the $L/V^{1/3}$ and B/T plane, as shown in figure 5. In the equation *(2)* the $L/V^{1/3}$ and B/T variables will be called *x* and *y* respectively.

$$sf1(x,y) = p00 + p10 \cdot x + p01 \cdot y + p20 \cdot x^2 + p11 \cdot x \cdot y + p02 \cdot y^2 + p30 \cdot x^3 + p21 \cdot x^2 \cdot y + p12 \cdot x \cdot y^2 + p03 \cdot y^3 \quad (2)$$

Table 4. The surface coefficients at different Froude number:

FR	0.150	0.175	0.200	0.225	0.250	0.275	0.300	0.325	0.350
P00	18.52	14.24	9.28	5.359	3.877	5.853	11.65	20.37	29.75
P10	-6.498	-5.013	-3.229	-1.864	-1.539	-2.657	-5.291	-8.813	-11.87
P01	-3.006	-2.042	-0.9369	0.07464	0.8564	1.31	1.498	1.601	2.00
P20	0.7634	0.5884	0.3739	0.2161	0.201	0.3823	0.7658	1.249	1.619
p11	0.6524	0.4615	0.2305	0.02007	-0.1234	-0.1761	-0.1572	-0.1292	-0.221
P02	0.3089	0.2253	0.1306	0.03857	-0.04786	-0.1172	-0.1658	-0.1902	-0.1896
P30	-0.02725	-0.02069	-0.01216	-0.00603	-0.006273	-0.01546	-0.03386	-0.05639	-0.07247
P21	-0.05172	-0.03874	-0.02523	-0.0141	-0.007606	-0.00613	-0.00807	-0.00977	-0.00445
P12	0.003709	0.003999	0.009709	0.01761	0.02503	0.02886	0.02841	0.02586	0.02733
P03	-0.03186	-0.02416	-0.01851	-0.01434	-0.01059	-0.00656	-0.00237	0.000298	-0.0023

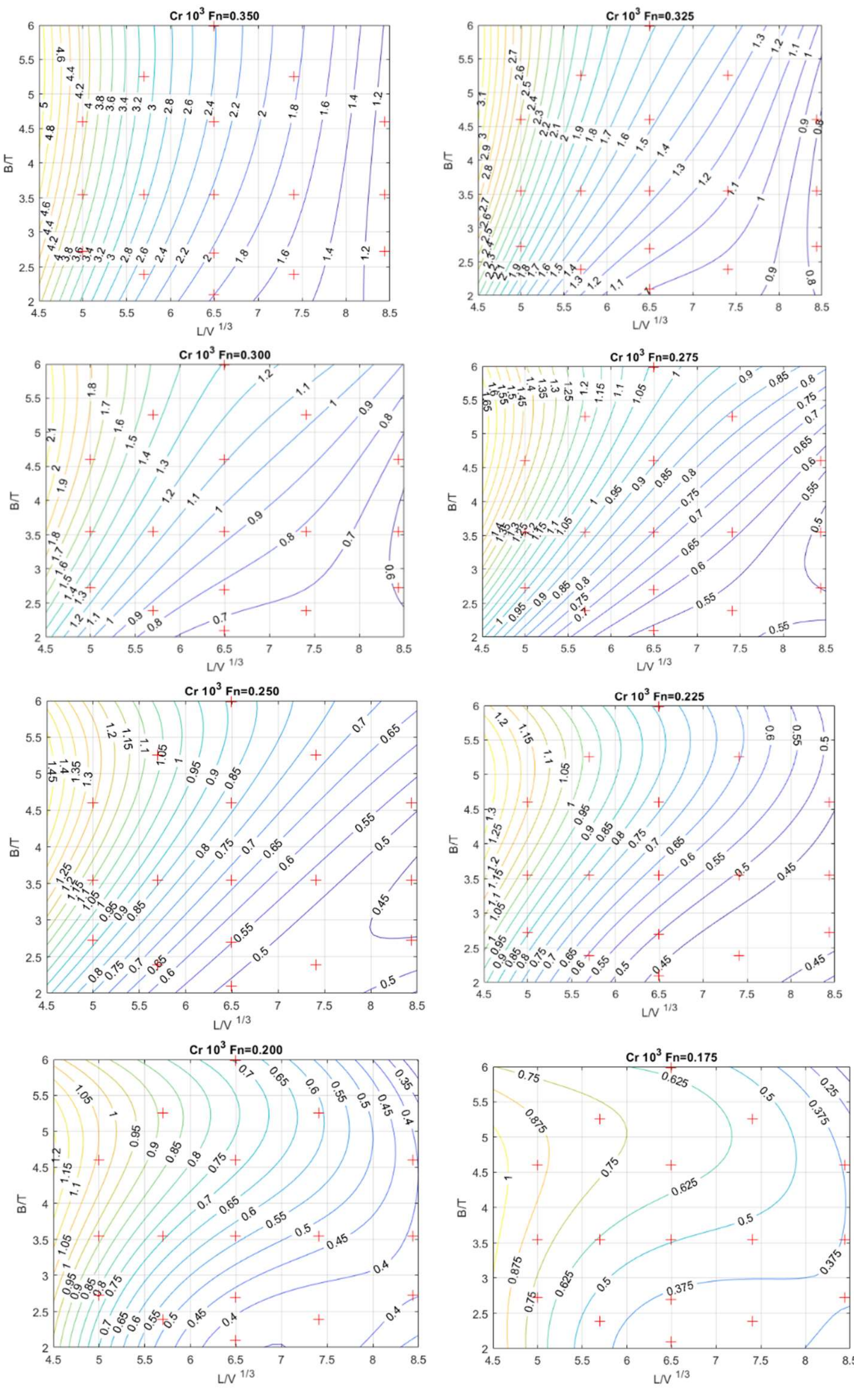

Figure 5. Iso-levels of CR at fixed Froude Number, in the $L/V^{1/3}$ B/T plane

The error evaluation of the residual resistance coefficient is good for all the speeds, as shown in the figure 6.

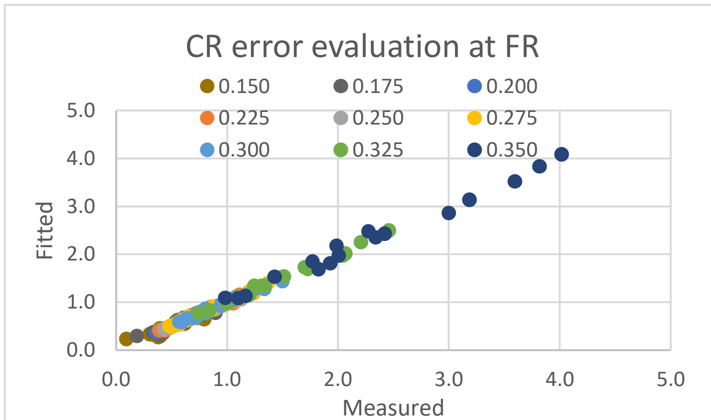

Figure 6. The measured and the fitted CR data at different Froude Number

5. The best shape

If the graphs provided so far can help us predict the resistance of the ship to be drawn, nothing can tell us about the best form of the Serie. To obtain this indication, it's necessary to compare hulls of the same volume moving at the same speed, regardless of their length, that's to say with the same Froude volumetric number. For a 10000 m^3 volume ship, the region of the plane in which the slope becomes flat gives us the best form coefficient, and therefore the best $L/V^{1/3}$ will be greater than 6 and the best B/T will be smaller than 4, as can be seen in Figure 7, where are shown the total resistance results of a 10000 m3 volume ship, at 20 and 22 knots speed.

It is not a coincidence that the hull generating the whole Serie, the C.2054 with $L/V^{1/3}$=6.49 and B/T=3.54 is amongst the best.

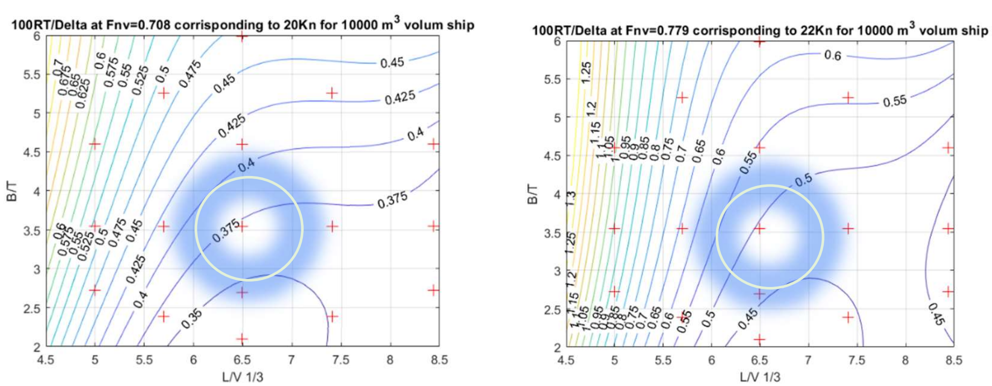

Figure 7. The 100·Rt/Delta ratio at 20 and 22 Knots Ship Speed

6. How to use the Ferry Series results

As written in the introduction, the seventeen models of the Ferry Series have been built with the scale ratio λ=28.750. All the ships are 10250.0 tons displacement and 10000 m^3 volume, CB=0.515, CM=0.943, CP=0.546, CW=0.715, CVP=0.720, LCB=-1.71%, XCF=-5.33%.

The model C.2054 has been used to build the whole Series, the variations in the forms have been obtained, operating the deformation of the hull in the x, y, z directions using the following parameters:

p = L derived hull / L generating hull
q = B derived hull / B generating hull
r = T derived hull / T generating hull

The derived models of the Series have all constant volume, while the product $p \cdot q \cdot r$ is $p \cdot q \cdot r = 1$, but we can design any size ship derived from the Series, of any displacement, and the product $p \cdot q \cdot r$ will be the ratio between the new displacement and the generating hull displacement of 10250 t.

Let's imagine you want to draw a 7500 t displacement ship, with a volume of 7317.1 m^3, and a maximum length of 110 meters $L \leq 110$ m, so that the ratio $L/V^{1/3} \leq 5.65$. If the immersion should be not greater than 6 meters $T \leq 6$ m, you can obtain a beam of 21.59 meters, remembering that the block coefficient is constant $C_b = V/(L*B*T) = 0.515$. Using this value for the block coefficient you can write the relation $B = V/(L*C_b*T)$ and, finally, the beam is B=7317.1/(110*0.515*6)=21.59 m . The wetted surface ratio $S/V^{2/3}$ can be now derived from relation (1)

$$S/V^{2/3} = 4.246+0.5085 \cdot L/V^{1/3}-0.5757 \cdot B/T-0.009741 \cdot (L/V^{1/3})^2+ \\ +0.03287 \cdot L/V^{1/3} \cdot B/T+0.06757 \cdot (B/T)^2 \qquad (1)$$

We can now write the table 5 with the new ship dimensions.

Table 5. The new ship dimensions:

Hull	L	B	T	p	q	r	$p \cdot q \cdot r$	$L/V^{1/3}$	B/T	$S/V^{2/3}$
	m	m	m	-	-	-	-	-	-	-
Generating Model	4.8634	0.7716	0.2177	$1/\lambda$	$1/\lambda$	$1/\lambda$	$1/\lambda^3$	6.493	3.544	6.657
Generating Hull	139.88	22.18	6.26	1	1	1	1	6.493	3.544	6.657
New Ship	109.66	21.59	6.00	0.784	0.973	0.958	0.732	5.150	4.000	6.062

With length-displacement ratio $L/V^{1/3}$=5.15 and the B/T=4.0 we can calculate the residual coefficient resistance at different Froude number from 0.150 to 0.375 using the coefficients in table 4; then with length, speed and viscosity we can calculate the frictional coefficient resistance and, according to ITTC 57 procedure [12] , we can obtain the total resistance as function of the speed.

Table 6. The new ship resistance coefficient as function of the speed:

FR	0.150	0.175	0.200	0.225	0.250	0.275	0.300	0.325	0.350
Vs (kn)	9.57	11.16	12.75	14.35	15.94	17.54	19.13	20.73	22.32
$CR \cdot 10^3$	0.554	0.637	0.735	0.815	0.884	0.974	1.185	1.733	2.926
$Cf \cdot 10^3$	1.692	1.659	1.630	1.606	1.585	1.566	1.549	1.533	1.519
$Ct \cdot 10^3$	2.246	2.296	2.365	2.421	2.469	2.540	2.733	3.266	4.446
Rts (t)	6.7	9.4	12.6	16.3	20.5	25.6	32.7	45.9	72.5

We are able now to draw the new ship total resistance curve as function of the speed, our target.

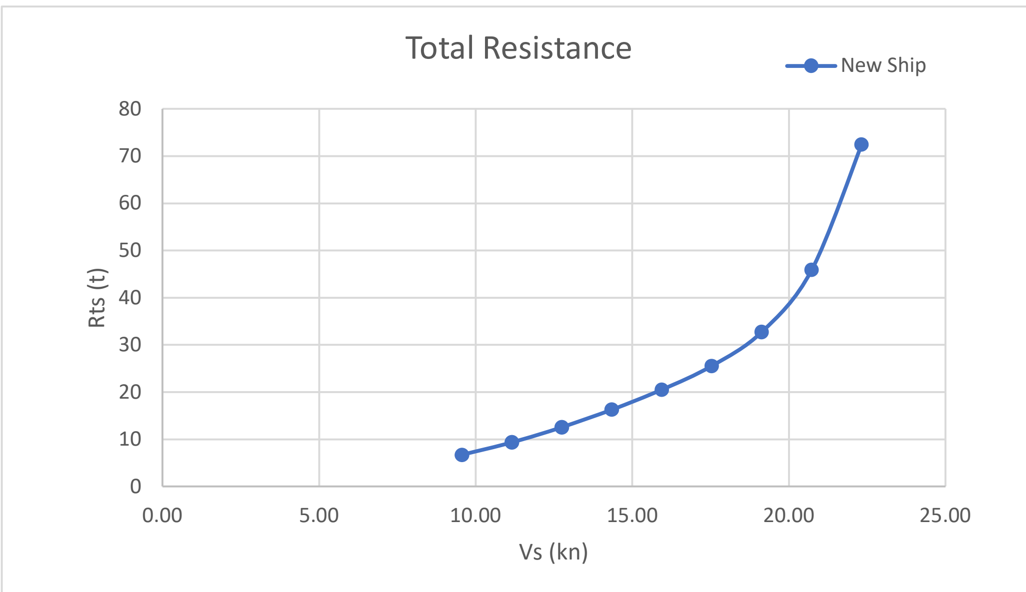

Figure 8. The New Ship Total Resistance Curve

Conclusions

The graphs and the equations provided so far can help the naval architect to predict the resistance of the ship to be drawn, indicating the best form of the Serie too. We hope our job can be interesting for any shipyard and ship designer. The simple use of these results has been our goal.

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