TUTORIAL – 1

Hydrostatic properties are given in model tests

Model Number	**Mxxx**	**42**
Loading Condition	**Design**	**Scale**
Length over all	L_{OA} (m)	199.868
Length between perpendiculars	L_{BP} (m)	183.430
Waterline Length	L_{WL} (m)	187.259
Breadth (at wl)	B_{WL} (m)	24.400
Draught (midship)	T (m)	8.000
Draught (AP)	T_A (m)	8.000
Draught (FP)	T_F (m)	8.000
Displacement volume	∇ (m^3)	25395.2
Displacement	Δ (ton)	26053.5
Wetted surface area	A_{WS} (m^2)	6153.73
Surface area of Bilge Keel	A_A (m^2)	141.95
Block coefficient	C_B	0.695
Prismatic coefficient	C_P	0.700
Midship area coefficient	C_M	0.993
Waterplane area coefficient	C_{WP}	0.857
Longitudinal centre of buoyancy	LCB (m) (from AP)	85.853
Longitudinal centre of floatation	LCF (m) (from AP)	78.234
Service speed	V_S (knots)	24.0

1. Determine the model speed if the ship's speed is 24 knots?

$$V_s = 24\,knots$$

$$\lambda = 1:42$$

$$V_m = V_s / \sqrt{\lambda} = 24 * 0.5144 / \sqrt{42}$$

$$\underline{V_m = 1.90\,m/s}$$

2. Determine the model L_{wl}, model S_w and model displacement Δ

$$(L_{WL})_{\text{MODEL}} = (L_{WL})_{\text{SHIP}} / \lambda = 187.259 / 42 = 4.459\,m$$

$$(S_{WS})_{\text{MODEL}} = (S_{WS})_{\text{SHIP}} / \lambda^2 = 6153.73 / 42^2 = 3.489\,m^2$$

$$(\Delta)_{\text{MODEL}} = (\nabla)_{\text{SHIP}} / \lambda^3 = 25395.2 / 42^3 = 0.343\,kg$$

3. Model resistance data was measured as (water temperature in the tank is 22 °C

V_m m/s	R_{tm} Kg
0.555	0.255
0.627	0.320
0.684	0.375
0.737	0.429
0.838	0.554
0.903	0.639
0.983	0.753
1.117	0.964
1.198	1.106
1.277	1.258
1.374	1.465
1.451	1.649
1.520	1.835
1.569	1.977
1.658	2.273
1.718	2.503
1.774	2.756
1.841	3.128
1.919	3.728
1.973	4.226
2.003	4.471

Determine the form factor (1+k). Form factor is determined according to Froude Number between 0.1 and 0.2. It should be draw a graph whose abscissa is Fn^4 /C_{FM} while ordinate is C_{TM}/$C_{FM.}$ Therefore, we need the following

$$Fr = \frac{V_M}{\sqrt{gL_{WL}}};C_{TM} = \frac{R_{TM}}{\frac{1}{2}\rho S_{WM} V_M^2};C_{FM} = \frac{0.075}{\left(\log\left(\mathrm{Re}\right)-2\right)^2}$$

Froude Number, Total resistance coefficient and friction coefficient should be calculated for each speed. Therefore, the range can be determined. And another unknown is appeared as Reynolds Number

$$\mathrm{Re} = \frac{V_M L_{WL}}{\upsilon}$$

The unknowns are the viscosity and density values of fresh and seawaters. Therefore ITTC Recommended procedures help us at this point. From https://ittc.info/ page it can be downloaded the Procedure no "75-02-01-03.pdf", "Fresh and sea water properties"

Temp t (°C)	Density ρ (kg/m³)	$\partial\rho/\partial t$ (kg/m³·°C)	Viscosity μ (Pa·s)	$\partial\mu/\partial t$ (Pa·s/°C)	$\nu = \mu/\rho$ (m²/s)	$\partial\nu/\partial t$ (m²/s·°C)	Pressure p_v (MPa)	$\partial p_v/\partial t$ (MPa/°C)
10	999.7025	-0.08791	0.001306	-3.760E-05	1.3063E-06	-3.749E-08	1.2282E-03	8.230E-05
21	997.9955	-0.21687	0.000978	-2.359E-05	9.7950E-07	-2.343E-08	2.4882E-03	1.530E-04
22	997.7735	-0.22708	0.000954	-2.270E-05	9.5653E-07	-2.253E-08	2.6453E-03	1.614E-04
23	997.5414	-0.23709	0.000932	-2.185E-05	9.3442E-07	-2.168E-08	2.8111E-03	1.702E-04

As a result

$$\upsilon = 0.95653E-6\, m^2/\mathrm{s} \quad \rho = 997.7735\,\mathrm{kg/m^3}$$

It is useful to produce an excel sheet because tabular format needs

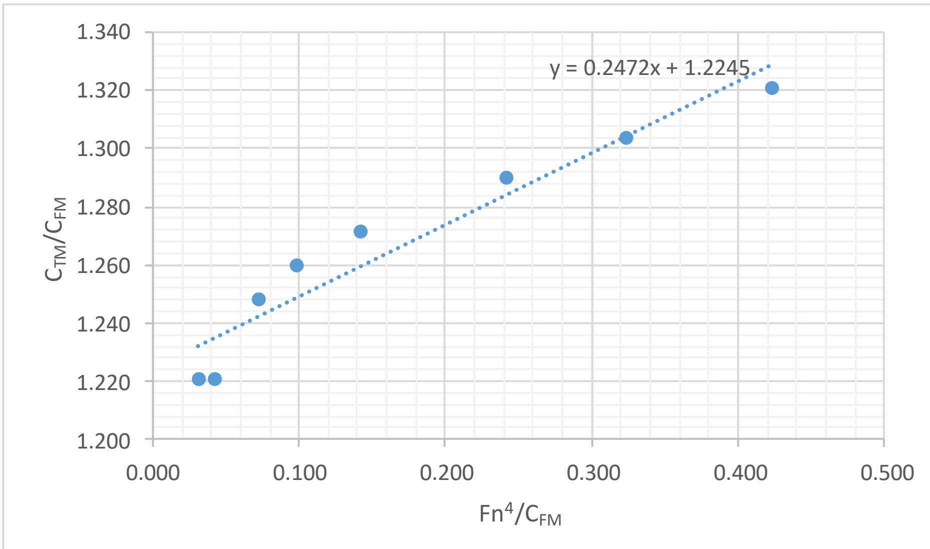
Scale - λ	42	(-)
ρ	997.7735	kg/m³
S_{wm}	3.489	m²
g	9.80665	m/s²
L_{wl}	4.459	m
$\nu * 10^{-6}$	0.95653	m²/s

V_M (m/s)	R_{TM} (Kg)	R_{TM} (N)	Fr (-)	Re (*10⁻⁶)	C_{TM} (*1000)	C_{FM} (*1000)
0.555	0.255	2.501	0.084	2.587	4.664	3.852
0.627	0.320	3.138	0.095	2.923	4.584	3.761
0.684	0.375	3.677	0.103	3.189	4.514	3.698
0.737	0.429	4.205	0.111	3.434	4.450	3.645
0.838	0.554	5.431	0.127	3.908	4.440	3.557
0.903	0.639	6.269	0.137	4.209	4.418	3.507
0.983	0.753	7.384	0.149	4.584	4.388	3.452
1.117	0.964	9.449	0.169	5.208	4.349	3.371
1.198	1.106	10.846	0.181	5.586	4.340	3.328
1.277	1.258	12.336	0.193	5.954	4.345	3.290
1.374	1.465	14.365	0.208	6.404	4.373	3.246
1.451	1.649	16.174	0.219	6.763	4.416	3.215
1.520	1.835	17.994	0.230	7.087	4.473	3.188
1.569	1.977	19.383	0.237	7.313	4.525	3.170
1.658	2.273	22.292	0.251	7.730	4.657	3.139
1.718	2.503	24.542	0.260	8.007	4.780	3.119
1.774	2.756	27.031	0.268	8.270	4.935	3.102

Fn^4/C_{FM} (-)	C_{TM}/C_{FM} (-)
0.013	1.211
0.022	1.219
0.031	1.221
0.042	1.221
0.073	1.248
0.099	1.260
0.142	1.271
0.242	1.290
0.324	1.304
0.423	1.321
0.574	1.347
0.720	1.374
0.876	1.403
0.999	1.427
1.260	1.484
1.459	1.532
1.670	1.591

1.841	3.128	30.680	0.278	8.583	5.199	3.081
1.919	3.728	36.558	0.290	8.948	5.701	3.059
1.973	4.226	41.446	0.298	9.197	6.118	3.044
2.003	4.471	43.845	0.303	9.340	6.275	3.036

1.951	1.687
2.321	1.864
2.602	2.010
2.775	2.067



Steps:

Step 01: Compute model resistance in Newton's.

$$R_{TM} = 0.255 * 9.80665 = 2.501\, N$$

Step 02: Compute Froude Number

$$Fr = \frac{V_M}{\sqrt{gL_{WL}}} = \frac{0.555}{\sqrt{9.80665 * 4.459}} = 0.084\,(-)$$

Step 03: Compute Reynolds Number (It should be multiplied by 1,000,000. Do not forget!)

$$\mathrm{Re} = \frac{V_M * L_{WL}}{\upsilon} = \frac{0.555 * 4.459}{0.95653} = 2.587\,(-)$$

Step 04: Compute total resistance coefficient (It should be multiplied by 1,000,000. Do not forget!)

$$C_{TM} = \frac{R_{TM}}{\frac{1}{2}\rho S_{WM} V_M^2} = \frac{2.501}{\frac{1}{2} * 997.7735 * 3.489 * 0.555^2}$$

$$= \frac{2.501}{536.153} = 4.664(*10^{-3})$$

Step 05: Compute skin friction coefficient –ITTC 1957 formula (It should be multiplied by 1,000. Do not forget!)

$$C_{FM} = \frac{0.075}{\left(\log_{10}(\mathrm{Re}) - 2\right)^2} = \frac{0.075}{\left(\log_{10}(2.587 * 1000000) - 2\right)^2}$$

$$= \frac{0.075}{\left(6.412 - 2\right)^2} = \frac{0.075}{19.4657} = 3.852(*10^{-3})$$

Step 06: Compute the value Fn^4/C_{FM}.

$$\frac{Fn^4}{C_{FM}} = \frac{0.084^4}{3.852 * 10^{-3}} = 0.013$$

Step 07: Compute the value $\mathbf{C_{TM}/C_{FM}}$

$$\frac{C_{TM}}{C_{FM}} = \frac{4.664}{3.852} = 1.210$$

These steps are performed for each speed to fulfill the whole speed array. Finally, a graph is plotted for the Froude Numbers between 0.1-0.2.

ITTC 1978 PERFORMANCE PREDICTION METHOD

Step 01: VM & RTM are both should be given. Test water temperature should also be known. Therefore Fr and Re cane be calculated

$$Fr = \frac{V_M}{\sqrt{gL_{WL}}} = \frac{0.555}{\sqrt{9.80665 * 4.459}} = 0.084(-)$$

$$\mathrm{Re} = \frac{V_M * L_{WL}}{\upsilon} = \frac{0.555 * 4.459}{0.95653\ (*)} = 2.587(-)$$

$$(*)\ \text{Tank water temperature at test day. It has also procedure.}$$

Step 02: C_{FM} is calculated according to ITTC 1957 line.

$$C_{FM} = \frac{0.075}{\left(\log_{10}(\mathrm{Re}) - 2\right)^2} = \frac{0.075}{\left(\log_{10}(2.587 * 1000000) - 2\right)^2} = 3.852(*10^{-3})$$

At this stage form factor (1+k) should be determined.

Step 03: C_{VM} is calculated. (Viscos resistance coefficient)

$$C_{VM} = C_{FM}\left(1+k\right) = 3.852(1+0.2) = 4.622(*10^3)$$

Step 04: $C_w$is calculated. (Wave resistance coefficient). Note that there is no “model” sub index because it remains the same with model and ship.

$$C_W = C_{TM} - C_{VM} = 4.664 - 4.622 = 0.043(*10^3)$$

INTERPRETATION OF THE RESULTS AT STANDARD WATER TEMPERATURE AT WHICH IS 15 DEGREES CELCIUS.

Step 05: The results should be converted to standard water temperature at which is 15 degrees celcius. Therefore Re is calculated for 15 degrees of water temperature.

$$\mathrm{Re} = \frac{V_M * L_{WL}}{\upsilon} = \frac{0.555 * 4.459}{1.138\ (*)} = 2.175(-)$$

$$(*)\ \text{For tank water temperature at}\ 15\,C^{\circ}.$$

Step 06: C_{FM} is re-calculated according to ITTC 1957 line.

$$C_{FM} = \frac{0.075}{\left(\log_{10}(\mathrm{Re}) - 2\right)^2} = \frac{0.075}{\left(\log_{10}(2.175*1000000) - 2\right)^2} = 3.987\,(*10^{-3})$$

Step 07: C_{VM} is re-calculated. (Viscos resistance coefficient)

$$C_{VM} = C_{FM}\left(1 + k\right) = 3.987\,(1 + 0.2) = 4.784\,(*10^{3})$$

Step 08: C_{TM} is re-calculated. (Total resistance coefficient)

$$C_{TM} = C_{VM} + C_W = 4.784 + 0.043 = 4.827(*10^{3})$$

$$\text{Note that } \mathrm{C_W} \text{ always is the same!!!}$$

Step 09: R_{TM} is re-calculated using newly calculated C_{TM}.

$$C_{TM} = \frac{R_{TM}}{\frac{1}{2}\rho S_{WM} V_M^2}$$

$$R_{TM} = C_{TM}\,\frac{1}{2}\rho S_{WM} V_M^2 = 4.827 * \frac{1}{2} * 999.1026 * 3.489 * 0.555^2$$

$$R_{TM} = 2.591(N)$$

As a result, model resistance values have been interpreted for standard temperature. From now on, the extrapolation procedure begins.

INTERPRETATION OF THE RESULTS AT FULL-SCALE

Step 10: V_S is ship speed which is calculated using model scale λ.

$$V_S = V_M * \sqrt{\lambda} = 0.555 * \sqrt{42} / 0.5144 = 6.992 \text{ knots}$$

Step 11: The Re is calculated for 15 degrees of standard salt water temperature for full scale.

$$\mathrm{Re} = \frac{V_S * L_{WL}}{\upsilon} = \frac{6.992 * 0.5144 * 4.459 * 42}{1.1892\ (*)} = 5.664 (*10^8)$$

$$(*) \text{ For standard salt water temperature at } 15 C^\circ .$$

Note that, Fr numbers are the same with model and ship scales. However, the Re's are different.

Step 12: C_{FS} is calculated according to ITTC 1957 line.

$$C_{FS} = \frac{0.075}{\left(\log_{10}(\mathrm{Re}) - 2\right)^2} = \frac{0.075}{\left(\log_{10}(5.664 * 100000000) - 2\right)^2} = 1.645 (*10^{-3})$$

Step 13: C_{VS} is calculated. (Ship scale viscos resistance coefficient)

$$C_{VS} = C_{FS}\left(1 + k\right) = 1.645(1 + 0.2) = 1.974 (*10^3)$$

Step 13: ΔC_F is calculated (Roughness effect) for 120 microns roughness height.

$$\Delta C_F = 105\left(\frac{k_S}{L_{WL}}\right)^{1/3} - 0.64 = 105\left(\frac{120/1000000}{4.459 * 42}\right)^{1/3} - 0.64$$

$$= 105 * 8.625 * 10^{-3} - 0.64 = 0.9056 - 0.64 = 0.265 (*10^3)$$

Step 14: C_{TS} is calculated. (Ship scale total resistance coefficient)

$$C_{TS} = \left(\frac{S + S_{BK}}{S}\right)\left(C_{VS} + \Delta C_F\right) + C_W = \left(\frac{3.489 * 42^2 + 77.74}{3.489 * 42^2}\right)\left(1.973 + 0.265\right) + 0.043 = 2.310 (*10^3)$$

$$C_{TS} = \left(1.01263\right)\left(2.238\right) + 0.043 = 2.310 (*10^3)$$

Note that C_W always is the same !!!

Step 15: R_{TS} is calculated using C_{TS}.

$$C_{TS} = \frac{R_{TS}}{\frac{1}{2}\rho S V_S^2}$$

$$R_{TS} = C_{TS}\frac{1}{2}\rho S V_S^2 = 2.310 * \frac{1}{2} * 1026.021 * 3.489 * 42^2 * \left(6.992 * 0.5144\right)^2$$

$$R_{TS} = 94.3(\mathrm{kN})$$

Step 16: Finally the effective power or towing resistance P_E is calculated using R_{TS}.

$$P_E = V_S * R_{TS} = (6.992 * 0.5144) * 94.3 = 339.16(\mathrm{kW})$$

Wind resistance, appendage resistance values are not incorporated!!!!