Andres Esteve Santos

Sailing Yacht & Powercraft Design SESS6066

17/03/2022

Assignment #2

Sailboat Hull Design

University of Southampton

Principal Dimensions & Hydrostatics

Hull Design Methodology

- Hull Fairing: The hull was faired using Maxsurf modeler according to meet the hydrostatic design specification. A personal choice to have a vertical bow and retro inclined transom with a classical arching freeboard line did not affect hydrostatic properties of the design.

- Appendage Addition: Appendages were created in the Wolfson Units Lines Processing Program (LPP) from this we were able to obtain key parameters for appendage resistance calculations and develop criteria for heeled hydrostatic parameters.

Hydostatic Parameters

Lowhe

Table 1: Hydrostatic and Geometric Parameters

Parameter	Value	Units
LOA	13.2	**m**
LWL	12.4	m
Minimum Freeboard	1.12	m
Displacement	8151	kg
Draft Amidships	0.546	m
Beam max extents on WL	3.2	m
Wetted Area (Sc)	30.883	m^2
Max sect. area	1.126	m^2
Waterpl. Area (Awl)	28.705	m^2
Prismatic coeff. (Cp)	0.57	n/a
Block coeff. (Cb)	0.368	n/a
LCB length	0.789	Aft of midships m
LCF length	0.968	Aft of midships m
LCB %	6.362%	Aft of midships % Lwl
LCF %	7.803%	Aft of midships % Lwl

Upright Resistance

Hull Resistance Calculation

Upright resistance for a yacht hull can be divided into two parameters residuary and frictional resistance.

Residuary Resistance:
The following equation 1 was used to calculate the residuary resistance at specific Froude numbers from the Delft series parameters a_0-a_8. Once Residuary resistance was obtained for the given Froude numbers interpolation to achieve the necessary values in 0.5 knot increments was needed. To interpolate a 6th order polynomial was fitted to the available points in the resistance curve for this specific yacht.

$$\frac{R_r}{\nabla_c 10^3 g} = a_0 + \left(a_1 \frac{LCB_{fpp}}{L_{wl}} + a_2 C_p + a_3 \frac{\nabla_c^{2/3}}{A_{wl}} + a_4 \frac{B_{wl}}{L_{wl}} \right) \frac{\nabla_c^{1/3}}{L_{wl}} + \left(a_5 \frac{\nabla_c^{2/3}}{S_c} + a_6 \frac{LCB_{fpp}}{LCF_{fpp}} + a_7 \left(\frac{LCB_{fpp}}{L_{wl}} \right)^2 + a_8 C_p^2 \right) \frac{\nabla_c^{1/3}}{L_{wl}} \quad \textbf{(1)}$$

Frictional Resistance:
Following recommendations by the ITTC, frictional resistance was calculated by the subsequent set of equations. All input parameters to these equations are listed in the hydrostatics table 1.

- Reynolds Number, evaluated with velocity in m/s and L=LWL=90% (For sailing yachts with different hull forms approximations to L can range anywhere between 70% to 90% of LWL) Kinematic viscosity ν is evaluated to be 1.0034 (mm^2 s) fresh water @20C°

$$Re = \frac{VL}{\nu} \quad \textbf{(2)}$$

- Subsequently the frictional correlation line can be obtained from equation 3.

$$Cf = \frac{0.075}{\left(Log(R_N) - 2 \right)^2} \quad \textbf{(3)}$$

- All values necessary can be computed in equation 4 to obtain the frictional resistance of the hull using $\rho = 1025 kg/m3$ and a Wetted surface area of $S_c = 30.8\, m2$

$$R_{friction} = \tfrac{1}{2} \rho V^2 C_f S_c \quad \textbf{(4)}$$

- Finaly we can obtain the frictional resistance by multiplying by the form factor. Hull shape will drive the form factor correction 1+k in this case was approximated to be 1.15 following similar designs.

$$R_f = R_{friction}(1 + k) \quad \textbf{(5)}$$

Figure 1 below visualized the resistance calculation at the specified speeds from 4 to 10kts in 0.5kts increments.

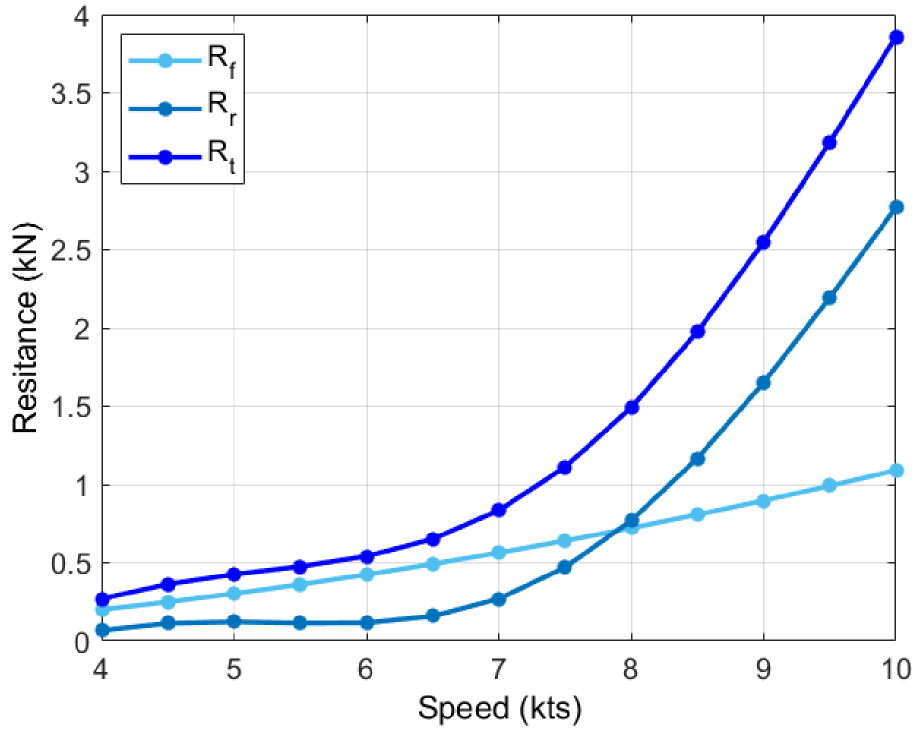

Figure 1:Hull Resitance Components Breakdown

Table 2: Hull Resitance Components Breakdown

V (kts)	Hull Rf (N)	Hulll Rr (N)	Hull Total (N)
4	201.2	69.1	270.4
4.5	249.9	113.3	363.2
5	303.4	122.7	426.1
5.5	361.6	114.7	476.3
6	424.5	116.7	541.1
6.5	491.9	159.3	651.2
7	564.0	270.2	834.2
7.5	640.6	470.0	1110.6
8	721.6	769.3	1490.9
8.5	807.1	1166.7	1973.8
9	897.0	1649.3	2546.3
9.5	991.3	2193.4	3184.7
10	1089.9	2767.7	3857.6

Appendage Resistance Calculation

For Rudder, Keel and Bulb resistance predictions the same method was used. The procedure follows equations 2-5. In the case for the appendages specific 1+k could be calculated by the theory of wing sections as outlined by equation 6. The obtained values are shown in table 2.

$$1 + k = 1 + 2(t/c) + 60(t/c)^4 \quad \textbf{(6)}$$

In order to adapt equations 2-5 used for the hull the Reynolds number for each appendage needs to be evaluated specifically for rudder, keel and bulb as outlined in table 2.

Table 3: Appendage Resitance Input Parameters

Appendage	(1+k)	L (for Re)	Value
Rudder	1.206	Avg Chord (m)	0.425
Keel	1.252	Avg Chord (m)	0.85
Bulb	1.492	Bulb Length (m)	2.5

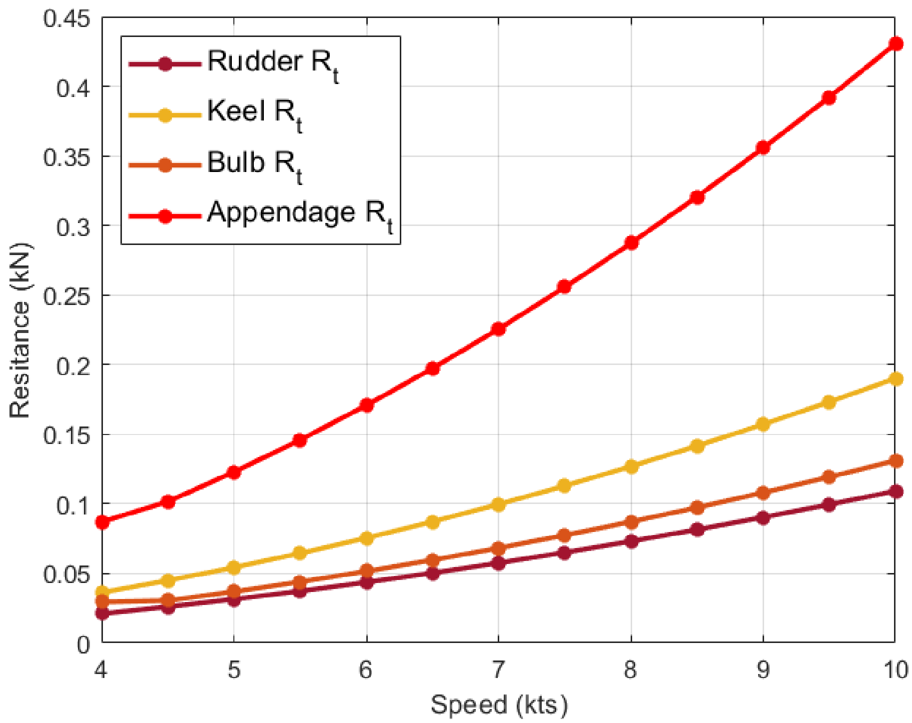

Figure 2: Appendage Resistance

Table 4: Individual Appendage Resitances

V (kts)	Rudder (N)	Keel (N)	Bulb(N)	Appendage Total (N)
4	21.2	36.4	29.5	87.0
4.5	26.1	45.0	30.5	101.6
5	31.5	54.3	37.0	122.9
5.5	37.4	64.5	44.0	145.9
6	43.7	75.5	51.6	170.7
6.5	50.4	87.2	59.7	197.3
7	57.5	99.7	68.3	225.5
7.5	65.1	112.9	77.5	255.5
8	73.1	126.9	87.2	287.2
8.5	81.5	141.6	97.4	320.5
9	90.4	157.1	108.1	355.5
9.5	99.6	173.2	119.3	392.1
10	109.2	190.1	131.1	430.4

Total Upright Resistance

Adding all of the afore mentioned resiatnace components we can obtain the total upright resistance for the yacht with equation 7.

$$R_{total} = \left(R_f(1+k) + R_r\right)_{hull} + \left(R_f(1+k)\right)_{rudder} + \left(R_f(1+k)\right)_{keel}\left(R_f(1+k)\right)_{bulb} \quad \textbf{(7)}$$

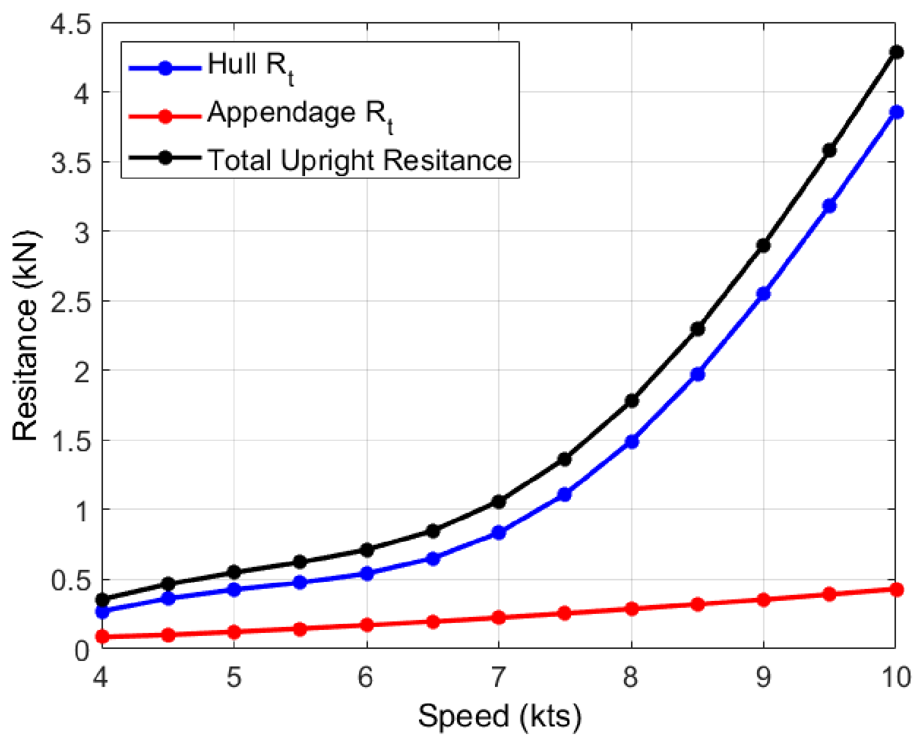

Figure 3: Total Upright Resistance

Table 5: Upright Resistance

V (kts)	Hull Total (N)	Appendage Total (N)	Total Resitance (N)
4	270.4	87.0	357.4
4.5	363.2	101.6	464.8
5	426.1	122.9	548.9
5.5	476.3	145.9	622.1
6	541.1	170.7	711.8
6.5	651.2	197.3	848.5
7	834.2	225.5	1059.7
7.5	1110.6	255.5	1366.1
8	1490.9	287.2	1778.1
8.5	1973.8	320.5	2294.4
9	2546.3	355.5	2901.8
9.5	3184.7	392.1	3576.8
10	3857.6	430.4	4288.0

Resistance and Heel

Thus far all resistance predictions have only dealt with upright drag, heeling will have a significant effect on the yachts resistance as the geometry will vary greatly with heel angle. Perhaps the most important parameters for the hull's residuary resistance in the Delft series are the Longitudinal Centre of Buoyancy (LCB) and Prismatic Coefficient (Cp) hence these should be optimized for the expected wind conditions at each heel angle.

Specially at high Froude numbers, Fn>0.35 (~7.5kts for the hull form in question) the effect of Beam to Draft Ratio (B/T) can have significant variations on resistance. "Beamier Shallow" boats having less resistance in contrast to the "Skinny Deep" boats

An aspect that should not be overlooked is the effect of Trim due to heel. When heeling the LCB could change the trim angle, specifically a bow-down trim could have catastrophic effects on performance at high Froude numbers.

Light Wind Performance Optimization

From figure 3 it is clearly apparent that the effect of appendage drag on total yacht performance is most evident at low Froude numbers where a yacht is expected to operate in light winds. To take advantage of this a sailing yacht that is particularly well suited for light winds should have additional analysis for rudder keel and bulb foil selection. Wetted surface area for appendages can be decreased thus increasing the aspect ratio of keels and rudder and decreasing depth will help decrease appendage drag. The drag reduction will not be significant however will improve.

Both Cp and LCB should be optimized for low Froude numbers and appear to the second order in the polynomial expression it may be assumed that both have an optimum value as a function of the speed under consideration.