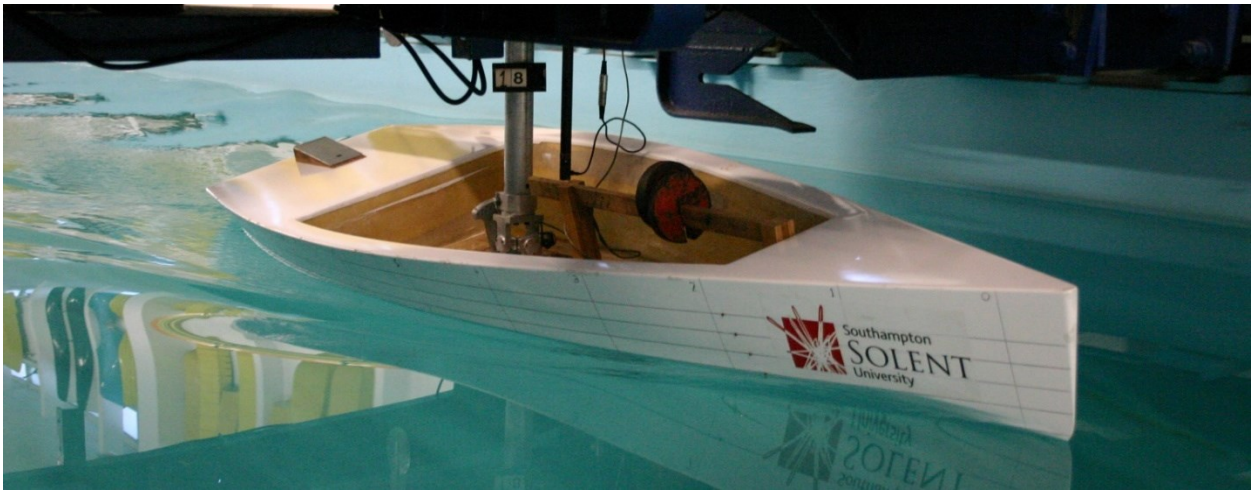
TOWING TANK TESTING ANALYSIS FOR A FARR-52 HULL FORM

YEP606 - ADVANCED NAVAL ARCHITECTURE



Abstract

The results of towing tank test on a 1:7 model scale Farr 52 hull form are presented. The tests were carried out at the Solent University facilities in a 60 m x 3.7 m x 1.8 m deep towing tank. Results are presented on three chosen sailing speeds, at three heel and leeway angles for each speed. The results of this tests provided the required data to analyze the heel drag and effective drag of the yacht. In addition, the analyzed results provide an insight into the effect of the heel angle to the heel drag and the effective draft components at a constant speed.

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Date: *14-Dec-18*

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1. Introduction

The aim of this document is to show the towing tank procedure and analysis results completed for a Farr 52 sailing yacht hull. The testing involves the use of a 1:7 scale model of the full scale yacht, comprising a hull, a keel and a bulb. The model was first calibrated to ensure that accurate results were obtained. Then, the model was tested for the upright condition, and then for the heeled and yawed conditions. 49 runs were completed in total.

2. Methodology

2.1. Upright Condition

On the upright condition the model is tested at different speeds with no leeway or heel angle. The different resistance components are then calculated based on the ITTC 1978 method [REF 1], where the upright resistance is assumed to be the sum of the viscous and wave drag. However, as the bulb and the keel are assumed to stay constantly immersed in the water, no wave drag is created by the appendages. Therefore, the upright resistance is defined to be as following:

Equation 1: ITTC 1978 method Upright Resistance

$$R_{UPRIGHT} = R_{VISCOUS\ KEEL} + R_{VISCOUS\ BULB} + R_{VISCOUS\ HULL} + R_{WAVE\ HULL}$$

Following the ITTC 1978 method, the viscous drag is assumed to be the friction drag, calculated using the ITTC 1957 friction line formula and the model Reynolds numbers, times the form factor (1+k). Then, the appendages drag is stripped out the total drag, so the left drag component is the bare hull total resistance.

The hull form factor $(1+k)_{HULL}$ is obtained using Prochaska's Plot technique, obtained by the intercept of a linear regression through a plot of the F_N^4/C_F against C_T/C_F. The keel and bulb form factors are deduced from the formulation proposed by S.F. Hoerner [REF 2], given in Equation 2.

Equation 2: S.F.Hoerner Appendage Form Factors

$$(1+K)_{KEEL} = 1 + 2\left[\frac{t}{c}\right] + 60\left[\frac{t}{c}\right]^4$$

$$(1+K)_{BULB} = 1 + 1.5\left[\frac{t}{c}\right]$$

Known the friction and total drag coefficients for the hull, the wave coefficient (C_W) can be obtained. Then, for the same Froude Number the C_W of the model is equal to the C_W full size. Full scale resistance values are then calculated using the ITTC 1978 method, calculating the full scale viscous resistance for all the components and the full scale wave resistance based on the model C_W.

2.2. Heeled and Yawed Conditions

On this condition the yacht is heeled and yawed to a certain angle. The fact that the yacht is heeled, involves changes in the wave making resistance, the waterline length, and the hull wetted surface area. This is translated as an increase in wave and frictional resistance. Also, as the yacht is sailing at a leeway angle (angle of attack), and therefore both the hull and the appendages contribute to produce lift, an additional drag component called the induced drag is generated. Therefore, the total resistance for this condition is given as:

Equation 3: Total Resistance for the Heeled and Yawed Condition

$$R_{TOTAL} = R_{UPRIGHT} + R_{HEELED} + R_{INDUCED}$$

The side force generated by the full size yacht is calculated based on the side force generated by the model. The model side force is scaled assuming the model lift coefficient equals the full size lift coefficient. Therefore, the full size side force can be calculated as follows:

Equation 4: Side Force Scaling

$$Side\ Force_{FULL\ SIZE} = Side\ Force_{MODEL} \times\ Scale\ Factor^3 \times \left({}^{\rho_{Seawater}}/_{\rho_{Tank\ Water}}\right)$$

Heeled resistance is calculated by subtracting the upright resistance from the *y intercept* of a strait line plot of the side force squared (x axis) against the total drag (y axis), plotted for a fixed yacht speed, heel, but a range of incrementally increasing yaw angles. The induced drag (D_I) is then obtained from slope of each regression lines times the side force squared.

Lastly, the effective draft (T_{EFF}) is calculated, which represents the equivalent span of a hull and keel combination. As the yacht operates in an air/water interface, the effective draft is mirrored and hence double as the hull acts as an endplate, based on the mirror boundary effect. Therefore, the span of the hull and keel combination is taken as 2 x T_{EFF}. As the side force and induced drag are known, the effective draft can be subtracted from the total drag on this condition. T_{EFF} is calculated as follows:

Equation 5: Effective Draft

$$T_{EFF} = \sqrt[2]{\frac{Side\ Force^2}{D_i \times \pi \times \rho \times V^2}}$$

3. Results

The (1+k) form factors have been established as explained in Section 2.2. As shown on Appendix 1, a hull form factor of 1.03 has been achieved plotting the range of $F_N{}^4/C_F$ values of up to 3 in the Prohaska plot. No values greater than 4 are plotted as the wave drag is dominant at those Froude numbers, hence not significant to establish the hull form factor. A bulb form factor of 1.31 and keel form factor of 1.21 are also achieved, based on Hoerner´s formulation (Equation 2).

On the upright condition the viscous drag of the hull and appendages result to produce the main resistance values at low speeds. At Froude numbers greater than 0.35 (8.3 knots for the full size yacht), the wave drag is the predominant drag component (see Appendix 2). The heel resistance shows negative values at the lower speeds, as the wave resistance in minimal at those speeds and the friction increase is not substantial in model scale. However, at the highest speed the heel resistance produces a considerable amount of drag.

There are a series of data errors associated with the towing tank results. Analyzing the sideforce results at different Froude numbers and comparing the increase in sideforce as the leeway angle increases for different heel angles, it is possible to see that at the highest speed run the measured sideforce overlaps between heel angles, where the 25 heel angle produces a slightly greater amount of sideforce than the 20 degrees heel condition (see Appendix 3). This error shows that the 20 degrees heel condition could have not been performed correctly at this speed, and instead of testing the model at 20 degrees a closer angle to 25 degrees might have been actually tested.

4. Effective Draft

Fn	TEFF / TMAX		
	Heel 15	Heel 20	Heel 25
0.2788	0.564	0.539	0.535
0.3259	0.524	0.488	0.469
0.4939	0.456	0.414	0.385
Fn	**Effective Draft**		
	Heel 15	**Heel 20**	**Heel 25**
0.2788	1.914	1.829	1.817
0.3259	1.778	1.656	1.591
0.4939	1.548	1.405	1.308

Tmax	3.39

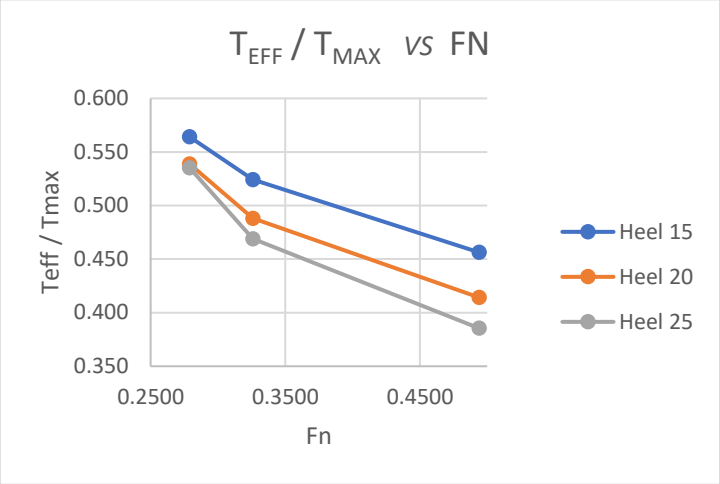


Figure 1: Effective Draft

The higher the effective draft the more efficient the keel is producing lift; hence the less induced drag will be per unit of sideforce generated. The results are presented for a range of heel angles at three Froude numbers. On the y-axis, the effective draft is divided by the maximum draft so as to non-dimensionalise the results.

5. Conclusions

The value of the effective draft reduces as the speed increases, as shown in Figure 1. If the yacht sailed in a homogeneous fluid then Equation 5 would be constant. However, because of the interface between air and water, both speed and heel affect the value of the effective draft. Also, as the yacht sails faster the mid-ship wave get deeper, and as the yacht heels the root of the keel moves closes to the free surface affecting the effective draft [REF 3]. Therefore, the effective draft results decreasing as the speed and heel angle increases can be said to be correct.

Heel drag increases as the heel and speed increases. However, at the highest Froude number the 20 degree heel condition shows to produce the least amount of heel drag. Due to the heel, the waterplane profile changes from a symmetrical profile at no heel angles, to an asymmetrical profile when the boat is heeled. However, it is very possible that the waterplane profile at 20 degrees of heel for this yacht is close to be symmetrical, as the heel drag drops at this heel angle.

All in all, analyzing the yacht resistance It is possible to stablish some likely upwind speeds for this yacht, based on the resistance curve of the yacht. Also, for the speed prediction it should be taken into account the racing background of the Farr 52 sailing yacht, assuming that the boat will be sailed in its optimum sail condition. Therefore, the likely upwind speeds of the yacht will be in the range of 0.2 to 0.47 in Froude number, based on the results shown in Appendix 5.

References

REF 1. ITTC (1978) Report of Performance Committee. In: Proceedings of 15th ITTC. Maritime Research Institute Netherlands, Wageningen, pp 359–392

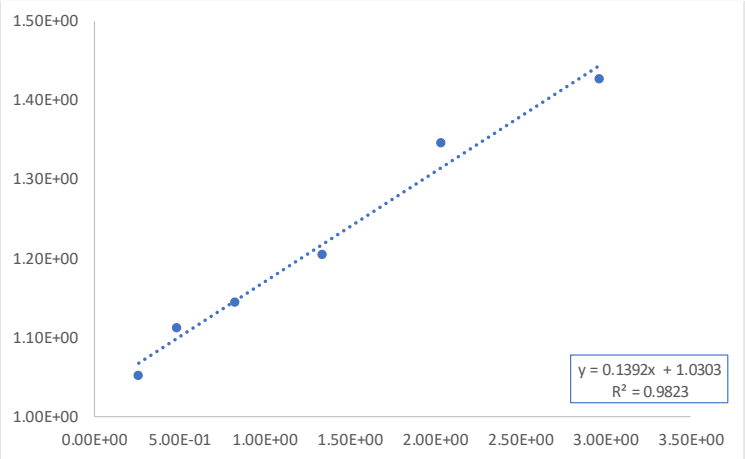
REF 2. S.F.Hoerner. Fluid Dynamic Drag. S.F. Hoerner, 1965

REF 3. Claughton, A. and Oliver, C. (2004). Design Consideration for Canting Keel Yachts. [PDF] Available at: http://www.wumtia.soton.ac.uk/sites/default/files/uploads/pages/HISWA2004AC.pdf [Accessed 13 Dec. 2018].

6. Appendix

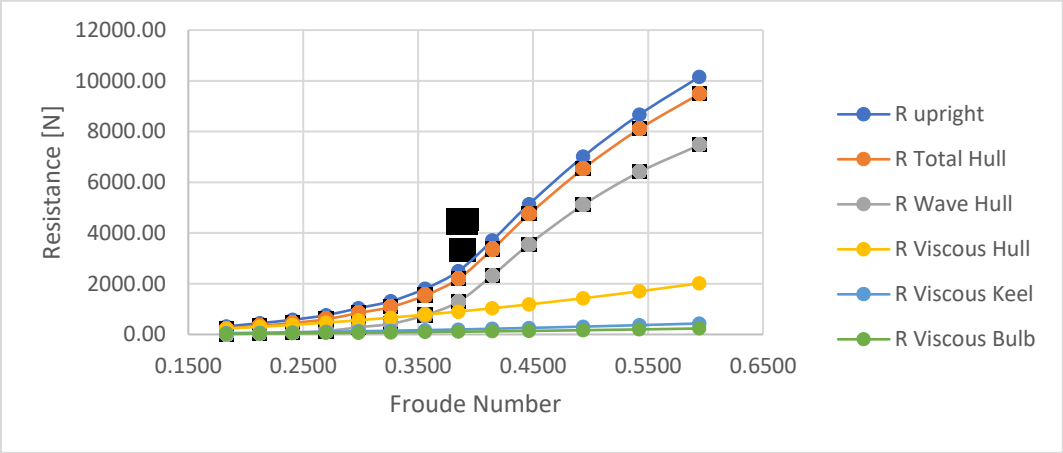
Appendix 1. Prohaska Plot

Prohaska Plot				
Speed *m/s*	Fn	RT_{MODEL} *N*	FN^4 / CF	CT / CF
0.8280	0.1831	1.5746	2.62E-01	1.05E+00
0.9610	0.2125	2.1346	4.90E-01	1.11E+00
1.0890	0.2408	2.7225	8.28E-01	1.14E+00
1.2210	0.2700	3.4673	1.34E+00	1.20E+00
1.3490	0.2983	4.5035	2.04E+00	1.35E+00
1.4760	0.3263	5.5352	2.97E+00	1.43E+00
1.6110	0.3562	7.2375	4.29E+00	1.64E+00
1.7420	0.3851	9.5182	5.95E+00	1.93E+00
1.8750	0.4146	13.2702	8.10E+00	2.45E+00
2.0200	0.4466	17.7118	1.11E+01	2.93E+00
2.2330	0.4937	23.6339	1.68E+01	3.30E+00
2.4540	0.5426	28.9870	2.50E+01	3.43E+00
2.6900	0.5947	33.9565	3.67E+01	3.40E+00

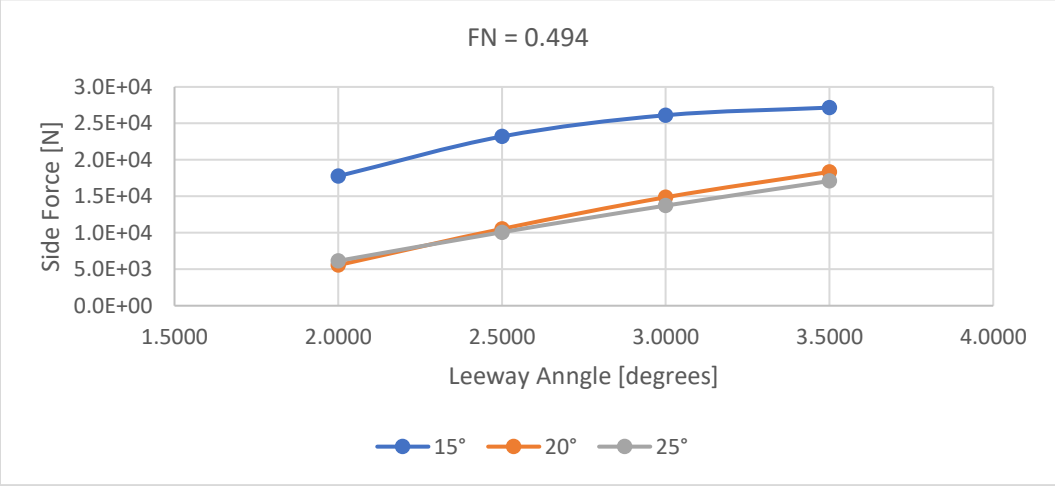


1 + k	1.0303

Appendix 2. Upright Resistance - Leeway: 0°



Appendix 3. Side Force at FN = 0.494 for Different Heel Conditions



Appendix 4. Towing Tank Results Scailing – Model

MODEL RESISTANCE															
TOWING TANK RESULTS					BULB CALCULATIONS			KEEL CALCULATIONS			BARE HULL CALCULATIONS				
Speed	Heel Angle	Yaw Angle	RT_{MODEL}	SF_{MODEL}	Reynols no.	CV_{BULB}	RV_{BULB}	Reynols no.	CV_{KEEL}	RV_{KEEL}	RT_{HULL}	CT_{HULL}	Reynols no.	CF_{HULL}	CW_{HULL}
m/s	*degrees*	*degrees*	*N*	*N*			*N*			*N*	*N*				
0.8280	0.0000	0.0000	1.5746	0.0000	2.28E+05	8.71E-03	1.48E-01	8.17E+04	1.07E-02	3.02E-01	1.12E+00	4.51E-03	1.51E+06	4.29E-03	9.12E-05
0.9610	0.0000	0.0000	2.1346	0.0000	2.65E+05	8.38E-03	1.92E-01	9.48E+04	1.02E-02	3.89E-01	1.55E+00	4.63E-03	1.76E+06	4.16E-03	3.40E-04
1.0890	0.0000	0.0000	2.7225	0.0000	3.00E+05	8.12E-03	2.39E-01	1.07E+05	9.84E-03	4.82E-01	2.00E+00	4.64E-03	1.99E+06	4.06E-03	4.63E-04
1.2210	0.0000	0.0000	3.4673	0.0000	3.36E+05	7.89E-03	2.92E-01	1.20E+05	9.53E-03	5.87E-01	2.59E+00	4.78E-03	2.23E+06	3.97E-03	6.92E-04
1.3490	0.0000	0.0000	4.5035	0.0000	3.72E+05	7.70E-03	3.48E-01	1.33E+05	9.27E-03	6.96E-01	3.46E+00	5.23E-03	2.47E+06	3.89E-03	1.22E-03
1.4760	0.0000	0.0000	5.5352	0.0000	4.07E+05	7.54E-03	4.07E-01	1.46E+05	9.04E-03	8.13E-01	4.31E+00	5.45E-03	2.70E+06	3.82E-03	1.51E-03
1.6110	0.0000	0.0000	7.2375	0.0000	4.44E+05	7.38E-03	4.75E-01	1.59E+05	8.83E-03	9.46E-01	5.82E+00	6.17E-03	2.95E+06	3.75E-03	2.30E-03
1.7420	0.0000	0.0000	9.5182	0.0000	4.80E+05	7.25E-03	5.45E-01	1.72E+05	8.64E-03	1.08E+00	7.89E+00	7.15E-03	3.19E+06	3.70E-03	3.34E-03
1.8750	0.0000	0.0000	13.2702	0.0000	5.16E+05	7.12E-03	6.21E-01	1.85E+05	8.47E-03	1.23E+00	1.14E+01	8.94E-03	3.43E+06	3.65E-03	5.18E-03
2.0200	0.0000	0.0000	17.7118	0.0000	5.56E+05	7.00E-03	7.08E-01	1.99E+05	8.31E-03	1.40E+00	1.56E+01	1.05E-02	3.70E+06	3.59E-03	6.82E-03
2.2330	0.0000	0.0000	23.6339	0.0000	6.15E+05	6.84E-03	8.46E-01	2.20E+05	8.09E-03	1.67E+00	2.11E+01	1.17E-02	4.08E+06	3.53E-03	8.02E-03
2.4540	0.0000	0.0000	28.9870	0.0000	6.76E+05	6.69E-03	1.00E+00	2.42E+05	7.90E-03	1.96E+00	2.60E+01	1.19E-02	4.49E+06	3.47E-03	8.32E-03
2.6900	0.0000	0.0000	33.9565	0.0000	7.41E+05	6.56E-03	1.18E+00	2.65E+05	7.72E-03	2.30E+00	3.05E+01	1.16E-02	4.92E+06	3.41E-03	8.08E-03
1.2610	15.0000	1.5000	4.0000	8.2150	3.47E+05	7.83E-03	3.09E-01	1.24E+05	9.44E-03	6.20E-01	3.07E+00	5.59E-03	2.31E+06	3.94E-03	1.53E-03
1.2610	15.0000	2.5000	3.9800	11.8900	3.47E+05	7.83E-03	3.09E-01	1.24E+05	9.44E-03	6.20E-01	3.05E+00	5.56E-03	2.31E+06	3.94E-03	1.50E-03
1.2610	15.0000	3.5000	4.4500	17.5000	3.47E+05	7.83E-03	3.09E-01	1.24E+05	9.44E-03	6.20E-01	3.52E+00	6.41E-03	2.31E+06	3.94E-03	2.35E-03
1.2610	15.0000	4.5000	4.8480	19.8103	3.47E+05	7.83E-03	3.09E-01	1.24E+05	9.44E-03	6.20E-01	3.92E+00	7.14E-03	2.31E+06	3.94E-03	3.08E-03
1.2610	20.0000	1.5000	3.9100	7.8200	3.47E+05	7.83E-03	3.09E-01	1.24E+05	9.44E-03	6.20E-01	2.98E+00	5.58E-03	2.31E+06	3.94E-03	1.52E-03
1.2610	20.0000	2.5000	3.8900	11.2900	3.47E+05	7.83E-03	3.09E-01	1.24E+05	9.44E-03	6.20E-01	2.96E+00	5.54E-03	2.31E+06	3.94E-03	1.48E-03
1.2610	20.0000	3.5000	4.4300	16.9100	3.47E+05	7.83E-03	3.09E-01	1.24E+05	9.44E-03	6.20E-01	3.50E+00	6.55E-03	2.31E+06	3.94E-03	2.49E-03
1.2610	20.0000	4.5000	4.7466	19.0119	3.47E+05	7.83E-03	3.09E-01	1.24E+05	9.44E-03	6.20E-01	3.82E+00	7.14E-03	2.31E+06	3.94E-03	3.08E-03
1.2610	25.0000	1.5000	3.8700	7.0200	3.47E+05	7.83E-03	3.09E-01	1.24E+05	9.44E-03	6.20E-01	2.94E+00	5.63E-03	2.31E+06	3.94E-03	1.57E-03
1.2610	25.0000	2.5000	3.8030	9.9150	3.47E+05	7.83E-03	3.09E-01	1.24E+05	9.44E-03	6.20E-01	2.87E+00	5.50E-03	2.31E+06	3.94E-03	1.44E-03
1.2610	25.0000	3.5000	4.2185	15.1427	3.47E+05	7.83E-03	3.09E-01	1.24E+05	9.44E-03	6.20E-01	3.29E+00	6.30E-03	2.31E+06	3.94E-03	2.24E-03
1.2610	25.0000	4.5000	4.5695	17.1219	3.47E+05	7.83E-03	3.09E-01	1.24E+05	9.44E-03	6.20E-01	3.64E+00	6.97E-03	2.31E+06	3.94E-03	2.91E-03
1.4740	15.0000	1.5000	5.7612	12.4600	4.06E+05	7.54E-03	4.06E-01	1.45E+05	9.04E-03	8.11E-01	4.54E+00	6.06E-03	2.70E+06	3.82E-03	2.12E-03
1.4740	15.0000	2.5000	5.7940	16.7910	4.06E+05	7.54E-03	4.06E-01	1.45E+05	9.04E-03	8.11E-01	4.58E+00	6.10E-03	2.70E+06	3.82E-03	2.16E-03
1.4740	15.0000	3.5000	6.2904	20.6455	4.06E+05	7.54E-03	4.06E-01	1.45E+05	9.04E-03	8.11E-01	5.07E+00	6.76E-03	2.70E+06	3.82E-03	2.83E-03
1.4740	15.0000	4.5000	6.8515	25.8784	4.06E+05	7.54E-03	4.06E-01	1.45E+05	9.04E-03	8.11E-01	5.63E+00	7.51E-03	2.70E+06	3.82E-03	3.57E-03
1.4740	20.0000	1.5000	5.5807	12.0243	4.06E+05	7.54E-03	4.06E-01	1.45E+05	9.04E-03	8.11E-01	4.36E+00	5.97E-03	2.70E+06	3.82E-03	2.04E-03
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1.4740	20.0000	3.5000	6.1545	19.6810	4.06E+05	7.54E-03	4.06E-01	1.45E+05	9.04E-03	8.11E-01	4.94E+00	6.76E-03	2.70E+06	3.82E-03	2.82E-03
1.4740	20.0000	4.5000	6.6639	24.3094	4.06E+05	7.54E-03	4.06E-01	1.45E+05	9.04E-03	8.11E-01	5.45E+00	7.46E-03	2.70E+06	3.82E-03	3.52E-03
1.4740	25.0000	1.5000	5.4650	10.8930	4.06E+05	7.54E-03	4.06E-01	1.45E+05	9.04E-03	8.11E-01	4.25E+00	5.95E-03	2.70E+06	3.82E-03	2.01E-03
1.4740	25.0000	2.5000	5.4854	13.9503	4.06E+05	7.54E-03	4.06E-01	1.45E+05	9.04E-03	8.11E-01	4.27E+00	5.98E-03	2.70E+06	3.82E-03	2.04E-03
1.4740	25.0000	3.5000	5.9666	17.7059	4.06E+05	7.54E-03	4.06E-01	1.45E+05	9.04E-03	8.11E-01	4.75E+00	6.65E-03	2.70E+06	3.82E-03	2.72E-03
1.4740	25.0000	4.5000	6.4547	22.1907	4.06E+05	7.54E-03	4.06E-01	1.45E+05	9.04E-03	8.11E-01	5.24E+00	7.34E-03	2.70E+06	3.82E-03	3.40E-03
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2.2340	15.0000	3.0000	31.3520	74.2870	6.15E+05	6.84E-03	8.46E-01	2.20E+05	8.09E-03	1.67E+00	2.88E+01	1.67E-02	4.09E+06	3.53E-03	1.31E-02
2.2340	15.0000	3.5000	32.4400	77.2580	6.15E+05	6.84E-03	8.46E-01	2.20E+05	8.09E-03	1.67E+00	2.99E+01	1.74E-02	4.09E+06	3.53E-03	1.37E-02
2.2340	20.0000	2.0000	24.2132	15.8314	6.15E+05	6.84E-03	8.46E-01	2.20E+05	8.09E-03	1.67E+00	2.17E+01	1.29E-02	4.09E+06	3.53E-03	9.30E-03
2.2340	20.0000	2.5000	25.3667	29.9616	6.15E+05	6.84E-03	8.46E-01	2.20E+05	8.09E-03	1.67E+00	2.29E+01	1.36E-02	4.09E+06	3.53E-03	9.98E-03
2.2340	20.0000	3.0000	26.6275	42.2943	6.15E+05	6.84E-03	8.46E-01	2.20E+05	8.09E-03	1.67E+00	2.41E+01	1.44E-02	4.09E+06	3.53E-03	1.07E-02
2.2340	20.0000	3.5000	28.1815	52.1820	6.15E+05	6.84E-03	8.46E-01	2.20E+05	8.09E-03	1.67E+00	2.57E+01	1.53E-02	4.09E+06	3.53E-03	1.17E-02
2.2340	25.0000	2.0000	24.9064	17.4930	6.15E+05	6.84E-03	8.46E-01	2.20E+05	8.09E-03	1.67E+00	2.24E+01	1.37E-02	4.09E+06	3.53E-03	1.00E-02
2.2340	25.0000	2.5000	25.9547	28.6664	6.15E+05	6.84E-03	8.46E-01	2.20E+05	8.09E-03	1.67E+00	2.34E+01	1.43E-02	4.09E+06	3.53E-03	1.07E-02
2.2340	25.0000	3.0000	27.2336	39.0429	6.15E+05	6.84E-03	8.46E-01	2.20E+05	8.09E-03	1.67E+00	2.47E+01	1.51E-02	4.09E+06	3.53E-03	1.14E-02
2.2340	25.0000	3.5000	28.6860	48.6411	6.15E+05	6.84E-03	8.46E-01	2.20E+05	8.09E-03	1.67E+00	2.62E+01	1.60E-02	4.09E+06	3.53E-03	1.23E-02

Appendix 5. Towing Tank Results Scailing - Full Size

FULL SIZE RESISTANCE CALCULATIONS																								
				BULB CALCULATIONS			KEEL CALCULATIONS			BARE HULL						Chart			RESULTS					
Fn	Speed	Heel Angle	Yaw Angle	Reynols no.	CV_{BULB}	RV_{BULB}	Reynols no.	CV_{KEEL}	RV_{KEEL}	Reynols no.	CV_{HULL}	RV_{HULL}	CW_{HULL}	RW_{HULL}	RT_{HULL}	SF^2	*y/x*	$y_{INTERCEPT}$	RT_{TOTAL}	SF	RU	Heel Drag	Induced Drag	T_{EFF}
	m/s	*degrees*	*degrees*			*N*			*N*			*N*		*N*	*N*				*N*		*N*	*N*	*N*	*m*
0.1831	2.1907	0.0000	0.0000	4.15E+06	4.60E-03	2.75E+01	1.49E+06	5.20E-03	5.17E+01	2.75E+07	2.61E-03	228.76	9.12E-05	7.99E+00	236.76				316.00		324.08			
0.2125	2.5426	0.0000	0.0000	4.81E+06	4.48E-03	3.61E+01	1.72E+06	5.04E-03	6.76E+01	3.20E+07	2.55E-03	300.96	3.40E-04	4.01E+01	341.04				444.65		410.80			
0.2408	2.8812	0.0000	0.0000	5.45E+06	4.38E-03	4.52E+01	1.95E+06	4.91E-03	8.46E+01	3.62E+07	2.50E-03	378.96	4.63E-04	7.02E+01	449.13				578.93		610.72			
0.2700	3.2305	0.0000	0.0000	6.12E+06	4.29E-03	5.57E+01	2.19E+06	4.80E-03	1.04E+02	4.06E+07	2.46E-03	467.99	6.92E-04	1.32E+02	599.84				759.43		798.02			
0.2983	3.5691	0.0000	0.0000	6.76E+06	4.21E-03	6.68E+01	2.42E+06	4.71E-03	1.24E+02	4.49E+07	2.42E-03	562.53	1.22E-03	2.85E+02	847.36				1038.45		988.07			
0.3263	3.9051	0.0000	0.0000	7.39E+06	4.14E-03	7.87E+01	2.65E+06	4.62E-03	1.46E+02	4.91E+07	2.39E-03	664.22	1.51E-03	4.21E+02	1085.70				1310.58		1279.16			
0.3562	4.2623	0.0000	0.0000	8.07E+06	4.08E-03	9.23E+01	2.89E+06	4.54E-03	1.71E+02	5.36E+07	2.35E-03	780.82	2.30E-03	7.62E+02	1542.82				1806.31		1808.80			
0.3851	4.6089	0.0000	0.0000	8.73E+06	4.02E-03	1.06E+02	3.13E+06	4.48E-03	1.97E+02	5.79E+07	2.33E-03	902.24	3.34E-03	1.30E+03	2198.64				2502.23		2602.31			
0.4146	4.9608	0.0000	0.0000	9.39E+06	3.97E-03	1.22E+02	3.36E+06	4.41E-03	2.25E+02	6.24E+07	2.30E-03	1033.78	5.18E-03	2.33E+03	3360.76				3707.69		3680.02			
0.4466	5.3444	0.0000	0.0000	1.01E+07	3.92E-03	1.39E+02	3.63E+06	4.35E-03	2.58E+02	6.72E+07	2.28E-03	1186.56	6.82E-03	3.55E+03	4741.22				5138.37		5061.75			
0.4937	5.9080	0.0000	0.0000	1.12E+07	3.85E-03	1.67E+02	4.01E+06	4.27E-03	3.09E+02	7.43E+07	2.24E-03	1428.57	8.02E-03	5.11E+03	6538.84				7015.30		7080.90			
0.5426	6.4927	0.0000	0.0000	1.23E+07	3.79E-03	1.99E+02	4.40E+06	4.19E-03	3.67E+02	8.16E+07	2.21E-03	1701.49	8.32E-03	6.40E+03	8103.03				8668.67		8649.68			
0.5947	7.1171	0.0000	0.0000	1.35E+07	3.73E-03	2.35E+02	4.83E+06	4.12E-03	4.33E+02	8.95E+07	2.18E-03	2017.19	8.08E-03	7.47E+03	9485.70				10154.19		10160.72			
0.2788	3.3363	15.0000	1.5000	6.32E+06	4.26E-03	5.91E+01	2.26E+06	4.77E-03	1.10E+02	4.19E+07	2.44E-03	471.84	1.53E-03	2.96E+02	767.97	8.34E+06	7.61E-06	835.943	937.13	2888.19	852.66	-16.71	63.51	1.914
0.2788	3.3363	15.0000	2.5000	6.32E+06	4.26E-03	5.91E+01	2.26E+06	4.77E-03	1.10E+02	4.19E+07	2.44E-03	471.84	1.50E-03	2.89E+02	760.94	1.75E+07	7.61E-06	835.943	930.10	4180.23	852.66	-16.71	133.04	1.914
0.2788	3.3363	15.0000	3.5000	6.32E+06	4.26E-03	5.91E+01	2.26E+06	4.77E-03	1.10E+02	4.19E+07	2.44E-03	471.84	2.35E-03	4.54E+02	926.18	3.79E+07	7.61E-06	835.943	1095.34	6152.56	852.66	-16.71	288.19	1.914
0.2788	3.3363	15.0000	4.5000	6.32E+06	4.26E-03	5.91E+01	2.26E+06	4.77E-03	1.10E+02	4.19E+07	2.44E-03	471.84	3.08E-03	5.94E+02	1066.09	4.85E+07	7.61E-06	835.943	1235.25	6964.82	852.66	-16.71	369.31	1.914
0.2788	3.3363	20.0000	1.5000	6.32E+06	4.26E-03	5.91E+01	2.26E+06	4.77E-03	1.10E+02	4.19E+07	2.44E-03	459.42	1.52E-03	2.85E+02	744.54	7.56E+06	8.34E-06	815.610	913.69	2749.32	852.66	-37.05	63.07	1.829
0.2788	3.3363	20.0000	2.5000	6.32E+06	4.26E-03	5.91E+01	2.26E+06	4.77E-03	1.10E+02	4.19E+07	2.44E-03	459.42	1.48E-03	2.78E+02	737.50	1.58E+07	8.34E-06	815.610	906.66	3969.28	852.66	-37.05	131.46	1.829
0.2788	3.3363	20.0000	3.5000	6.32E+06	4.26E-03	5.91E+01	2.26E+06	4.77E-03	1.10E+02	4.19E+07	2.44E-03	459.42	2.49E-03	4.68E+02	927.35	3.53E+07	8.34E-06	815.610	1096.51	5945.13	852.66	-37.05	294.92	1.829
0.2788	3.3363	20.0000	4.5000	6.32E+06	4.26E-03	5.91E+01	2.26E+06	4.77E-03	1.10E+02	4.19E+07	2.44E-03	459.42	3.08E-03	5.79E+02	1038.66	4.47E+07	8.34E-06	815.610	1207.82	6684.09	852.66	-37.05	372.79	1.829
0.2788	3.3363	25.0000	1.5000	6.32E+06	4.26E-03	5.91E+01	2.26E+06	4.77E-03	1.10E+02	4.19E+07	2.44E-03	448.99	1.57E-03	2.88E+02	737.36	6.09E+06	8.45E-06	817.690	906.52	2468.06	852.66	-34.97	51.50	1.817
0.2788	3.3363	25.0000	2.5000	6.32E+06	4.26E-03	5.91E+01	2.26E+06	4.77E-03	1.10E+02	4.19E+07	2.44E-03	448.99	1.44E-03	2.65E+02	713.81	1.22E+07	8.45E-06	817.690	882.97	3485.87	852.66	-34.97	102.74	1.817
0.2788	3.3363	25.0000	3.5000	6.32E+06	4.26E-03	5.91E+01	2.26E+06	4.77E-03	1.10E+02	4.19E+07	2.44E-03	448.99	2.24E-03	4.11E+02	859.88	2.83E+07	8.45E-06	817.690	1029.04	5323.81	852.66	-34.97	239.63	1.817
0.2788	3.3363	25.0000	4.5000	6.32E+06	4.26E-03	5.91E+01	2.26E+06	4.77E-03	1.10E+02	4.19E+07	2.44E-03	448.99	2.91E-03	5.34E+02	983.30	3.62E+07	8.45E-06	817.690	1152.46	6019.61	852.66	-34.97	306.36	1.817
0.3259	3.8998	15.0000	1.5000	7.38E+06	4.14E-03	7.85E+01	2.65E+06	4.62E-03	1.46E+02	4.90E+07	2.39E-03	629.43	2.12E-03	5.59E+02	1188.69	1.92E+07	6.456E-06	1252.402	1413.01	4380.62	1273.26	-20.86	123.89	1.778
0.3259	3.8998	15.0000	2.5000	7.38E+06	4.14E-03	7.85E+01	2.65E+06	4.62E-03	1.46E+02	4.90E+07	2.39E-03	629.43	2.16E-03	5.71E+02	1200.23	3.48E+07	6.46E-06	1252.402	1424.56	5903.30	1273.26	-20.86	224.98	1.778
0.3259	3.8998	15.0000	3.5000	7.38E+06	4.14E-03	7.85E+01	2.65E+06	4.62E-03	1.46E+02	4.90E+07	2.39E-03	629.43	2.83E-03	7.45E+02	1374.75	5.27E+07	6.46E-06	1252.402	1599.07	7258.43	1273.26	-20.86	340.13	1.778
0.3259	3.8998	15.0000	4.5000	7.38E+06	4.14E-03	7.85E+01	2.65E+06	4.62E-03	1.46E+02	4.90E+07	2.39E-03	629.43	3.57E-03	9.43E+02	1572.04	8.28E+07	6.46E-06	1252.402	1796.36	9098.18	1273.26	-20.86	534.40	1.778
0.3259	3.8998	20.0000	1.5000	7.38E+06	4.14E-03	7.85E+01	2.65E+06	4.62E-03	1.46E+02	4.90E+07	2.39E-03	612.87	2.04E-03	5.23E+02	1136.00	1.79E+07	7.45E-06	1192.791	1360.33	4227.43	1273.26	-80.47	133.06	1.656
0.3259	3.8998	20.0000	2.5000	7.38E+06	4.14E-03	7.85E+01	2.65E+06	4.62E-03	1.46E+02	4.90E+07	2.39E-03	612.87	2.06E-03	5.28E+02	1140.71	3.01E+07	7.45E-06	1192.791	1365.04	5485.16	1273.26	-80.47	224.02	1.656
0.3259	3.8998	20.0000	3.5000	7.38E+06	4.14E-03	7.85E+01	2.65E+06	4.62E-03	1.46E+02	4.90E+07	2.39E-03	612.87	2.82E-03	7.25E+02	1337.74	4.79E+07	7.45E-06	1192.791	1562.06	6919.34	1273.26	-80.47	356.48	1.656
0.3259	3.8998	20.0000	4.5000	7.38E+06	4.14E-03	7.85E+01	2.65E+06	4.62E-03	1.46E+02	4.90E+07	2.39E-03	612.87	3.52E-03	9.04E+02	1516.83	7.30E+07	7.45E-06	1192.791	1741.15	8546.56	1273.26	-80.47	543.86	1.656
0.3259	3.8998	25.0000	1.5000	7.38E+06	4.14E-03	7.85E+01	2.65E+06	4.62E-03	1.46E+02	4.90E+07	2.39E-03	598.95	2.01E-03	5.05E+02	1104.36	1.47E+07	8.06E-06	1182.643	1328.68	3829.71	1273.26	-90.61	118.28	1.591
0.3259	3.8998	25.0000	2.5000	7.38E+06	4.14E-03	7.85E+01	2.65E+06	4.62E-03	1.46E+02	4.90E+07	2.39E-03	598.95	2.04E-03	5.13E+02	1111.53	2.41E+07	8.06E-06	1182.643	1335.85	4904.57	1273.26	-90.61	193.99	1.591
0.3259	3.8998	25.0000	3.5000	7.38E+06	4.14E-03	7.85E+01	2.65E+06	4.62E-03	1.46E+02	4.90E+07	2.39E-03	598.95	2.72E-03	6.82E+02	1280.71	3.87E+07	8.06E-06	1182.643	1505.03	6224.94	1273.26	-90.61	312.50	1.591
0.3259	3.8998	25.0000	4.5000	7.38E+06	4.14E-03	7.85E+01	2.65E+06	4.62E-03	1.46E+02	4.90E+07	2.39E-03	598.95	3.40E-03	8.53E+02	1452.31	6.09E+07	8.06E-06	1182.643	1676.63	7801.69	1273.26	-90.61	490.86	1.591
0.4939	5.9106	15.0000	2.0000	1.12E+07	3.85E-03	1.68E+02	4.01E+06	4.27E-03	3.09E+02	7.43E+07	2.24E-03	1358.27	1.10E-02	6.67E+03	8028.63	3.16E+08	3.71E-06	7364.738	8505.48	17770.01	7089.48	275.26	1170.94	1.548
0.4939	5.9106	15.0000	2.5000	1.12E+07	3.85E-03	1.68E+02	4.01E+06	4.27E-03	3.09E+02	7.43E+07	2.24E-03	1358.27	1.26E-02	7.62E+03	8982.45	5.38E+08	3.71E-06	7364.738	9459.30	23203.95	7089.48	275.26	1996.57	1.548
0.4939	5.9106	15.0000	3.0000	1.12E+07	3.85E-03	1.68E+02	4.01E+06	4.27E-03	3.09E+02	7.43E+07	2.24E-03	1358.27	1.31E-02	7.94E+03	9295.35	6.82E+08	3.71E-06	7364.738	9772.20	26117.45	7089.48	275.26	2529.43	1.548
0.4939	5.9106	15.0000	3.5000	1.12E+07	3.85E-03	1.68E+02	4.01E+06	4.27E-03	3.09E+02	7.43E+07	2.24E-03	1358.27	1.37E-02	8.32E+03	9677.87	7.38E+08	3.71E-06	7364.738	10154.71	27161.98	7089.48	275.26	2735.80	1.548
0.4939	5.9106	20.0000	2.0000	1.12E+07	3.85E-03	1.68E+02	4.01E+06	4.27E-03	3.09E+02	7.43E+07	2.24E-03	1322.52	9.30E-03	5.49E+03	6807.71	3.10E+07	4.500E-06	7159.856	7284.56	5565.93	7089.48	70.38	139.41	1.405
0.4939	5.9106	20.0000	2.5000	1.12E+07	3.85E-03	1.68E+02	4.01E+06	4.27E-03	3.09E+02	7.43E+07	2.24E-03	1322.52	9.98E-03	5.89E+03	7213.25	1.11E+08	4.500E-06	7159.856	7690.10	10533.75	7089.48	70.38	499.33	1.405
0.4939	5.9106	20.0000	3.0000	1.12E+07	3.85E-03	1.68E+02	4.01E+06	4.27E-03	3.09E+02	7.43E+07	2.24E-03	1322.52	1.07E-02	6.33E+03	7656.53	2.21E+08	4.500E-06	7159.856	8133.38	14869.62	7089.48	70.38	995.00	1.405
0.4939	5.9106	20.0000	3.5000	1.12E+07	3.85E-03	1.68E+02	4.01E+06	4.27E-03	3.09E+02	7.43E+07	2.24E-03	1322.52	1.17E-02	6.88E+03	8202.88	3.37E+08	4.500E-06	7159.856	8679.73	18345.87	7089.48	70.38	1514.60	1.405
0.4939	5.9106	25.0000	2.0000	1.12E+07	3.85E-03	1.68E+02	4.01E+06	4.27E-03	3.09E+02	7.43E+07	2.24E-03	1292.50	1.00E-02	5.78E+03	7070.08	3.78E+07	5.20E-06	7370.135	7546.93	6150.10	7089.48	280.65	196.53	1.308
0.4939	5.9106	25.0000	2.5000	1.12E+07	3.85E-03	1.68E+02	4.01E+06	4.27E-03	3.09E+02	7.43E+07	2.24E-03	1292.50	1.07E-02	6.15E+03	7438.65	1.02E+08	5.2E-06	7370.135	7915.50	10078.39	7089.48	280.65	527.76	1.308
0.4939	5.9106	25.0000	3.0000	1.12E+07	3.85E-03	1.68E+02	4.01E+06	4.27E-03	3.09E+02	7.43E+07	2.24E-03	1292.50	1.14E-02	6.60E+03	7888.26	1.88E+08	5.2E-06	7370.135	8365.11	13726.51	7089.48	280.65	978.98	1.308
0.4939	5.9106	25.0000	3.5000	1.12E+07	3.85E-03	1.68E+02	4.01E+06	4.27E-03	3.09E+02	7.43E+07	2.24E-03	1292.50	1.23E-02	7.11E+03	8398.91	2.92E+08	5.2E-06	7370.135	8875.76	17101.00	7089.48	280.65	1519.49	1.308

Appendix 6. Upright Resistance vs Side Force [2]