IX International Conference on Computational Methods in Marine Engineering
MARINE 2021
I.M. Viola and F. Brennan (Eds)

ALTERNATE METHOD FOR DETERMINING RESISTANCE OF SHIP WITH FOULED HULL

MARINE 2021

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Key words: Towing tank setup, Biofouling roughness.

Abstract. Recent research shows that planks of various roughness can be towed in water, and the frictional resistance obtained can be extended to hull forms. Thus, the resistance is determined experimentally with the help of towing tank setup. The estimation of resistance of planks of varied roughness by towing them in the towing tank will help determine frictional resistance of the ship.

In the studies of Schultz (Schultz 2007), it is reported that higher drag values are reported for small coverage of barnacles, and smaller drag values are reported for large coverage. The skin friction coefficients for different plate lengths are extrapolated to ship size and speed. Usually, the variation in drag coefficients is minimal for planks of length above 50 feet.

1 INTRODUCTION

Recent papers have reported a lot of work on extending the frictional resistance from planks to ships (Demirel et al. 2017). Biofouling is a major research area where the resistance has to be estimated based on a lot of parameters and extrapolated to ship hulls (Uzun et al. 2020). Towing a unit plank and pasting various roughness conditions for estimating ship resistance with roughness condition is explained in the paper.

One of the other approaches tried in the paper is the estimation of ship resistance with various roughness condition across the ship hull. There have been many studies where the heterogenous roughness difference in ship hulls has been incorporated in resistance calculations. In the paper, a formula has been proposed to calculate the ΔC_f values with various roughness condition. This will help to estimate the average ΔC_f values for a given ship configuration with different fouling conditions across the hull. Databases have been reported for ship hull fouling penalty calculations (Hunsucker et al. 2014), with different hull fouling conditions. In this paper, modelling of roughness functions for different fouling conditions has also been done.

Biofilm community structure on ship has also been widely studied (Zargiel, Coogan, and Swain 2011). In their paper the different biofouling community diatom distribution across the ship has been tabulated in the literature. Community structure has been tabulated in commercially available ship hull coatings and in-service ships.

2 METHODOLOGY

C_{TM} is calculated corresponding to each speed, from the model test results as follows (Ghose and Gokarn 2004).

$$.C_{TM} = \frac{R_{TM}}{\frac{1}{2}\rho_M {V_M}^2 S_M} \qquad (1)$$

where R_{TM} - total model resistance, ρ_M - density of water, V_M - model speed and S_M – model wetted surface area.

The frictional resistance coefficient C_{FM} is calculated for each speed as follows.

$$C_{FM} = \frac{0.075}{(\log_{10} R_{n_M} - 2)^2} \qquad (2)$$

where R_{nM} - Reynold's number.

The residuary resistance coefficient is obtained at each speed with the following equation,

$$C_{RM} = C_{TM} - (1 + k)C_{FM} \qquad (3)$$

where k – form factor. Here form factor of 1.05 (Ghose and Gokarn 2004) was considered for calculations.

The resistance of the bare hull is determined in the towing tank and skin friction for roughness is determined using Townsin formulae (Townsin 2003). To simulate the effect of the various biofouling growth stages, the ΔC_F or correlation allowance factor (also denoted by C_A) was varied. Hence, the viscous resistance co-efficient has to be added with "roughness allowance" or the correlation allowance as per equation 4 below.

$$\Delta C_F = \left[105\left(\frac{k_s}{L}\right)^{1/3} - 0.64\right]10^{-3} \qquad (4)$$

Here k_s - average amplitude of roughness of the wetted surface of the ship, the typical value for the hull roughness is $150*10^{-6}$. L - waterline length of the hull in m.

Given below is the recent version of the ITTC 1978 method.

$$10^3 \Delta C_F = 44 \left[\left[\frac{k_s}{L} \right]^{\frac{1}{3}} - 10 R_n{}^{\frac{1}{3}} \right] + 0.125 \qquad (5)$$

Calculations were also carried out by employing Granville’s method in this paper. The recent article on this approach (Song, Demirel, and Atlar 2020), reported the increase in the frictional drag was estimated by using Granville's approach for the calculation of ΔC_F values. An increase in frictional resistance using Granville's method is accepted by researchers to arrive at the frictional resistance of the prototype based on resistance of plank and Reynold's number. Granville's similarity law is relied upon and is discussed in the chapter.

3 EXPERIMENTAL SETUP AND SAMPLE PREPARATION

To simulate the various biofouling conditions, various sand particles of different sizes were stuck on the plywood plank 1.18mm, 2.36mm, and 4.75mm in varying ratios, as shown below in Fig. 1. All the towing tank experiments were performed at the towing tank at IIT Madras. Thus the biofouling ratios considered were of no foul, min fouling, medium fouling, and maximum fouling conditions, respectively**.** The sand height varied from 100 μm to 400 μm.

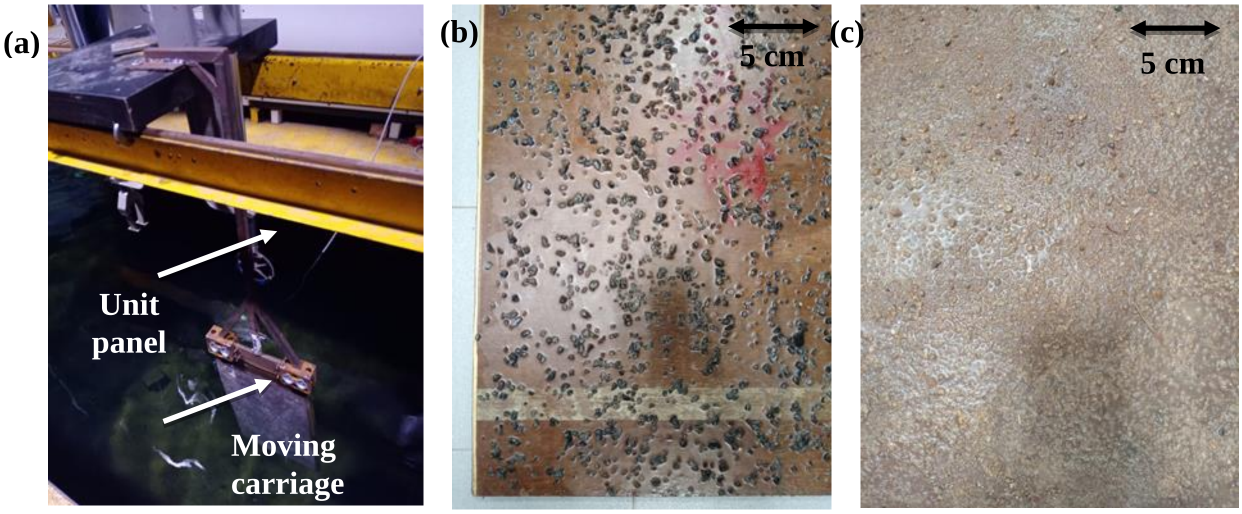

Fig. 1: (a) Fabricated towing tank setup (b) Coarse roughness on plank (c) Fine roughness on plank

The sand was stuck with the help of resin. The resin weight was appropriately weighed (30g:30g:30g for sand 60g:60g:60g for planks of size 1m*1m) so that the sand would be stuck properly even in towing tank experiments with varying speeds.

4 TOWING TANK SETUP

The towing tank setup was designed as given in Fig. 2 below. The load cell was placed in the vertical position, and the setup will deploy the panel in the towing tank such that the water forces act along the surface of the plank. This is done so that the forces acting on the plank are minimum, and only the forces are accounted for which act along the surface of the plank. The immersed plank area dimensions are 0.5 m by 1m, so that the total surface area of the plank comes up to 1 m^2. The load cell used for the setup was of 10 kg capacity. The load cell was also provided with additional support with the help of a clamp joint. Ball-bearing support was given for maintaining the plank's position during towing, with the help of double angle joint at an angle of 30º. The setup was fabricated, and it was tested in the towing tank. The experiments with various velocities were done in the towing tank.

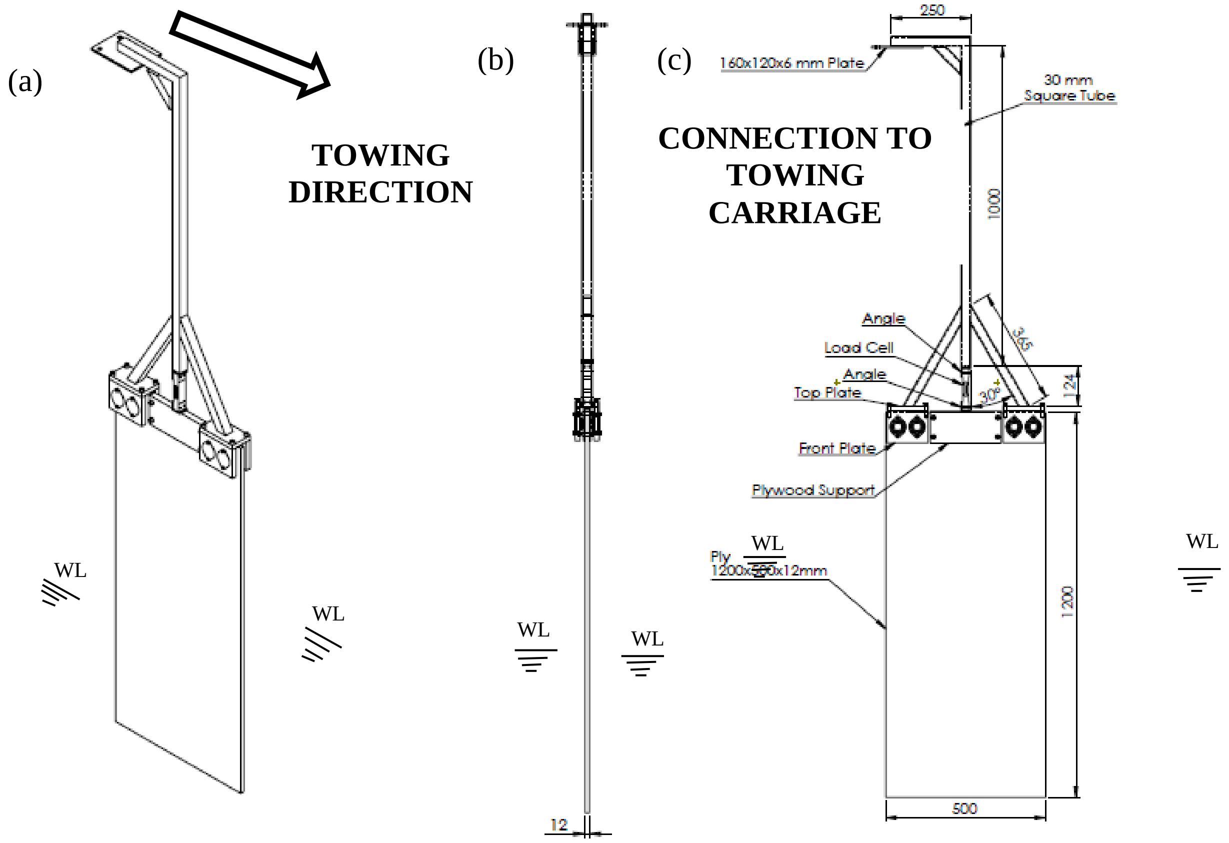

Fig 2: Towing tank test setup (a) Perspective (b) Body plan (c) Profile view

5 RESULTS AND DISCUSSION

Below shown in Fig. 3 is the resistance curves for different fouling condition of planks as shown in Table 1. The resistance tests were conducted in towing tank. The towing speeds were varied from 0.2 m/s to 1.2 m/s. It was found that the frictional resistance is found to increase with the increase in roughness with fouling conditions. The resistance was also found to increase with speed.

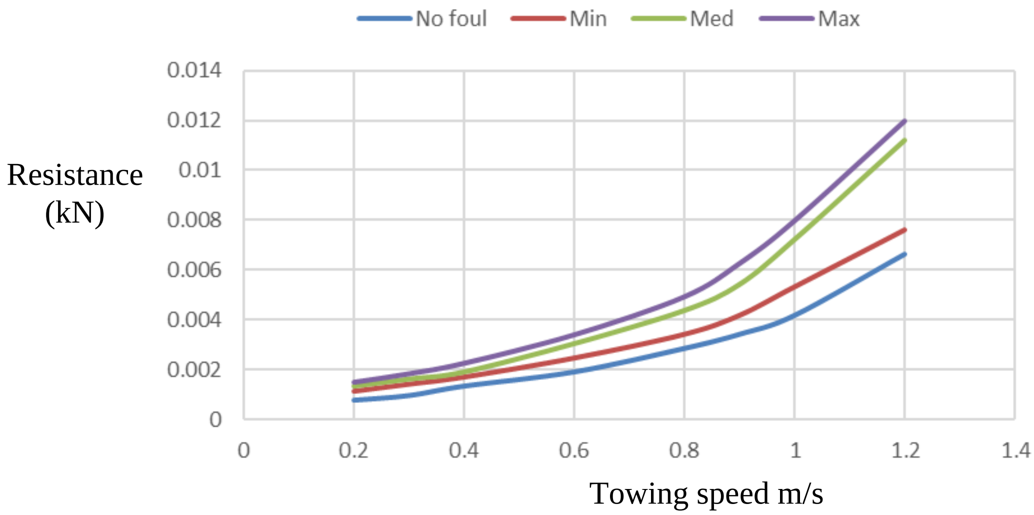

Fig 3: Frictional resistance plots for different fouling conditions as given in Table 1 below

Table 1 Different fouling conditions

Description of condition	**Rt_{50}(μm)**	ΔC_F
Typical new anti-fouling coating	150	0.000168
Deteriorated coating/light slime	300	0.00044
Heavy slime	600	0.000725
Small calcareous fouling	1000	0.001313
Medium calcareous fouling	3000	0.001619
Heavy calcareous fouling	10000	0.00233

5.1 STEPS FOR CALCULATIONS

1) Calculate ΔC_F values for various roughness. C_r from experiment and find C_{ts1} using eqn 6

$$\Delta C_F = \left[105 * \frac{k_s}{L}^{1/3} - 0.64\right] * 10^{-3} \qquad (6)$$

2) Calculate ΔC_F values for various roughness. C_r from experiment and find C_{ts2} using eqn 7

$$10^3 \Delta C_F = 44\left[\frac{k_s}{L}^{1/3} - 10 {R_n}^{1/3}\right] + 0.125 \qquad (7)$$

3) Find C_{ts3} using Granville's method

Table 2 Calculation of C_{ts} using three different methods

C_f	**$\Delta C_{F\ gran}$**	**ΔC_F**	C_{ts1}	C_{ts2}	C_{ts3}
0.002	0.000168	0.0002	50.31657	50.1457	50.31654
0.00239	0.00044	0.0004	49.05145	48.91576	49.05149
0.002246	0.000725	0.0006	47.84964	47.73105	47.84977
0.002083	0.001619	0.0016	48.42364	48.31926	48.42366
0.002029		0.00162	49.26266	49.16802	49.26104

The calibration plot for the 10 kg load cell is given in the plot as in Fig. 4 below.

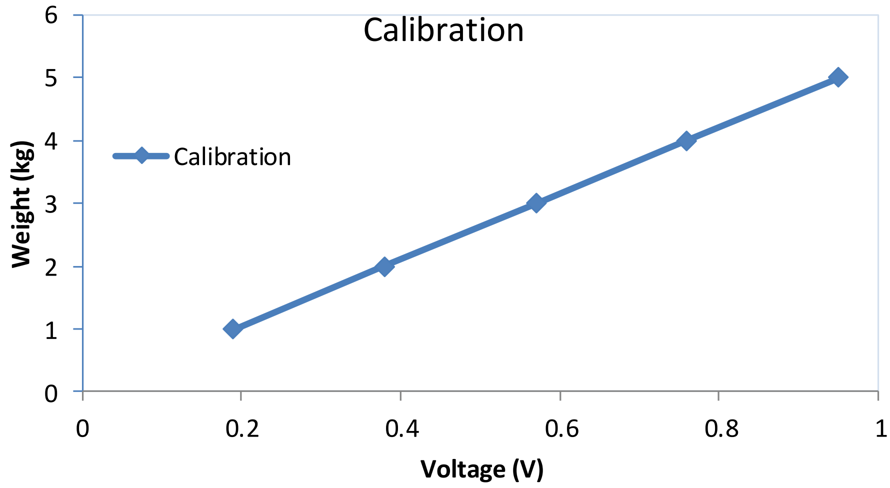

Fig 4: Calibration plots for 10 kg load cell

Table 3 Load cell calibration values

Weight kg	Load cell V
1	0.19
2	0.38
3	0.57
4	0.76
5	0.95

The calibration for the load cell is as given in Table 3 above. The force values were calculated from the voltage values. The constants were calculated corresponding to various speeds of the panel. At low speed, C_r can have lower values. This study proposes developing a new algorithm that can be employed for the resistance calculation for different biofouling conditions of the ship.

C_f values were calculated for all the towing speeds. The calculated C_f values are plotted in the graph in Fig 5.

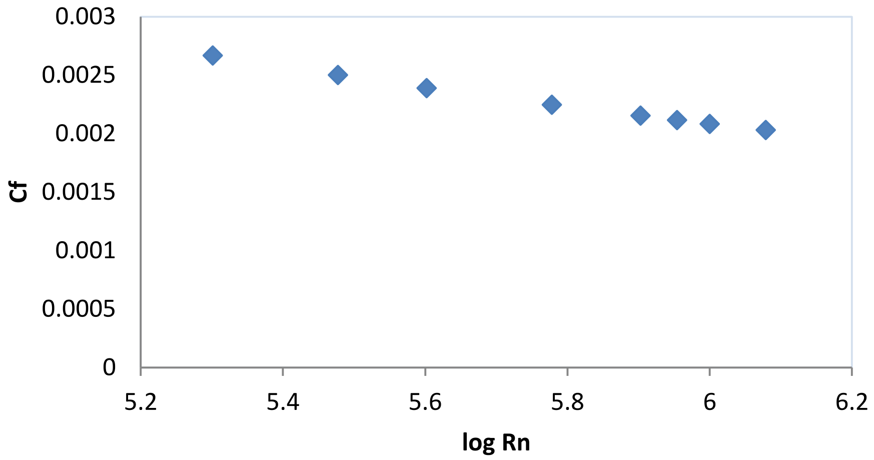

Fig 5: Calculated C_f values for various ship speeds

The non-dimensional resistance of the ship is found out from the towing tank experiments. The C_f values were calculated as per ITTC formula as already mentioned and both C_f and C_t are plotted and shown in Figs 6-8. Due to the additional ΔC_f value, the residual resistance will be reduced by ΔC_{fm}. This causes the C_{rm} value at A to be lesser. For the smaller C_{rm} value, of course, the speed will be less at point B. The difference remaining between the C_r and C_f curve is ΔC_f. By transposing the C_r value in the co-efficient curve, we can estimate the ship's minimum velocity due to the considered fouling condition. The methodology for calculation is depicted in Fig 6. In papers published, the C_F and C_V values were plotted from the smooth schoenerr line. The methodology proposed in this paper will help to estimate the average velocity with different fouling conditions from the frictional resistance co-efficients,

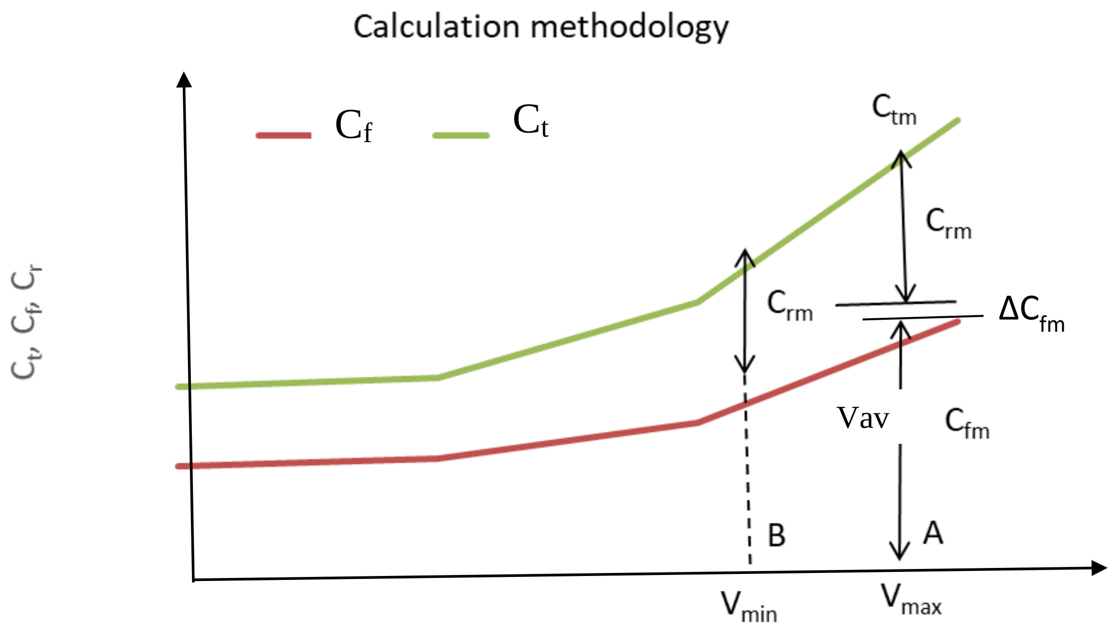

Fig. 6: Graph adopted for calculation

Each tow is at a speed, that is V_m for which C_r values were calculated. V_{low} was used for calculations.

$$C_{tm}-(C_{fm}+\Delta C_f)=C_r$$

Corresponding to different ship speeds, C_f values were also calculated.

$$C_f=.075/(\log R_n-2)^2$$

$$C_{fm}=.075/(\log R_n-2)^2, \text{ where } R_n = v*l/\nu.$$

The shifting for C_r values were done for different draft conditions, and it was found that the V_{avg} values are found to increase with the increase in the total resistance. Below given in Figs 7 and 8, are the graphs for design draft condition with V_a and V_b values where the C_t and C_f values are plotted.

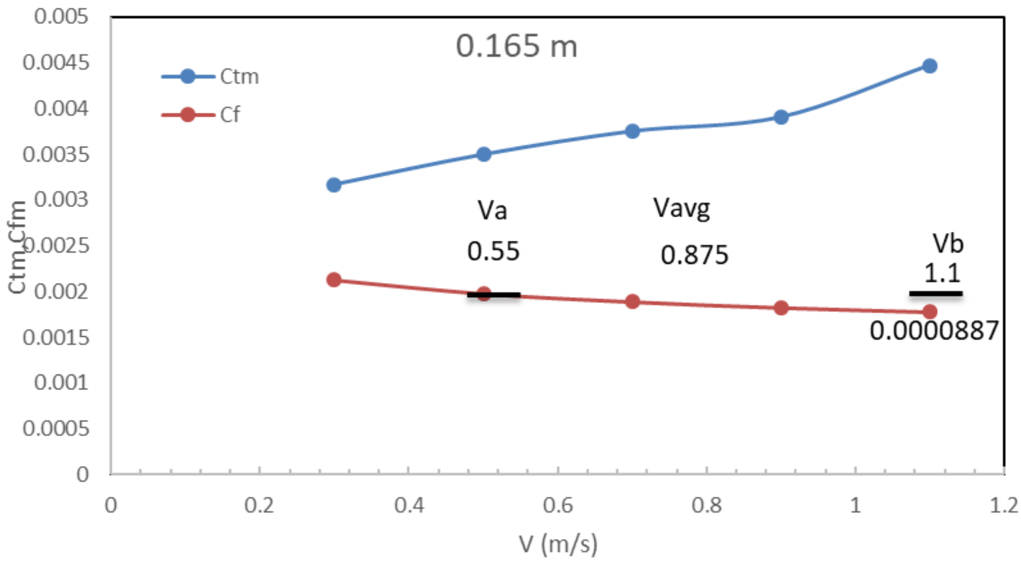

Fig 7: Calculated C_t and C_r values for 0.165m draft condition for V_b=1.1

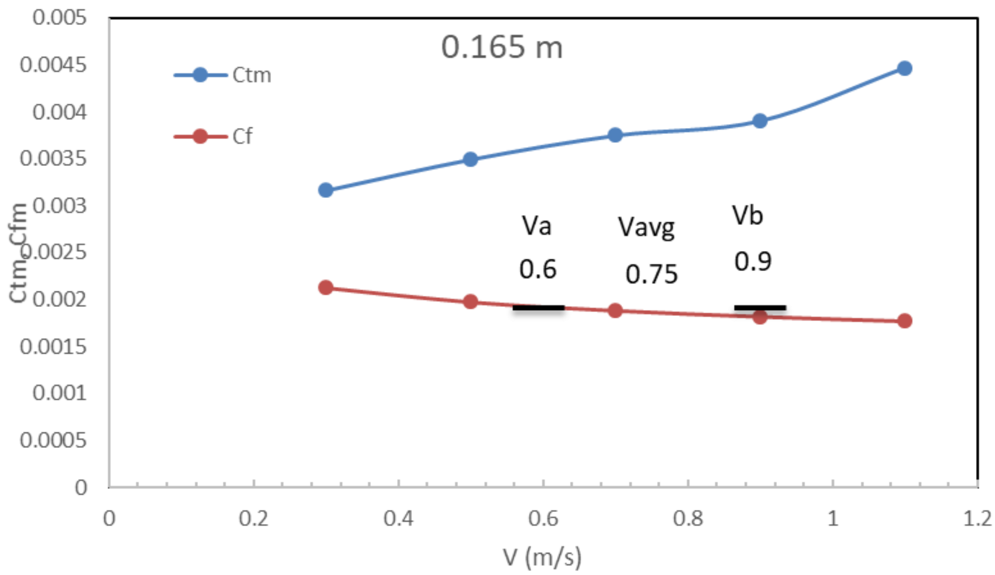

Fig 8: Calculated C_t and C_r values for 0.165m draft condition for V_b=0.9

Similarly, the plots were done for the three roughness conditions. The plot lines were shifted towards the C_f line such that the value of V_b was obtained. The average velocity was calculated, which was used for the resistance calculations. The speeds calculated for design draft 16.5 m are given in Fig 9. As the velocity increases, the V_{avg} speed is found to increase, as can be seen from the graphs.

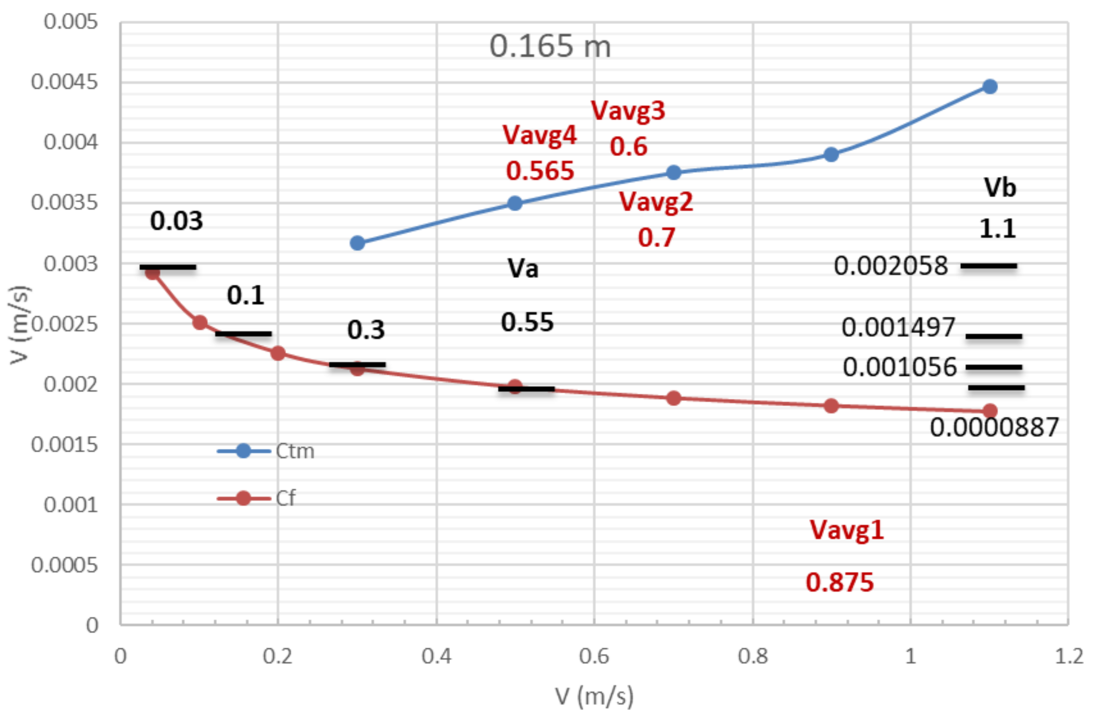

Fig 9: Calculated C_t and C_r values for 0.165m draft condition for V_b corresponding to different fouling conditions

The V_{avg} values are found to increase with the resistance values, as shown in Fig 10.

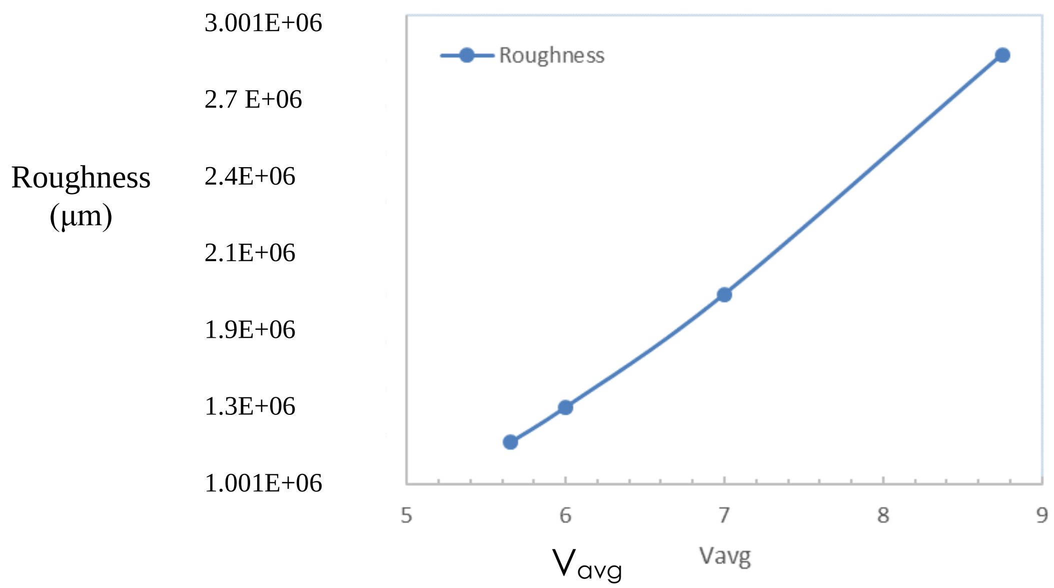

Fig 10: $V_{average}$ values for different total resistance values

Vs is unknown here. The calculations were repeated to calculate the R_{ts} values for different fouling conditions by accounting for varied roughness conditions. For each ΔC_f, three values plotted with C_{tm} of other method only slight difference as in Fig 11. R_{ts1}, R_{ts2} and R_{ts3} for each ΔC_f corresponds to plank roughness.

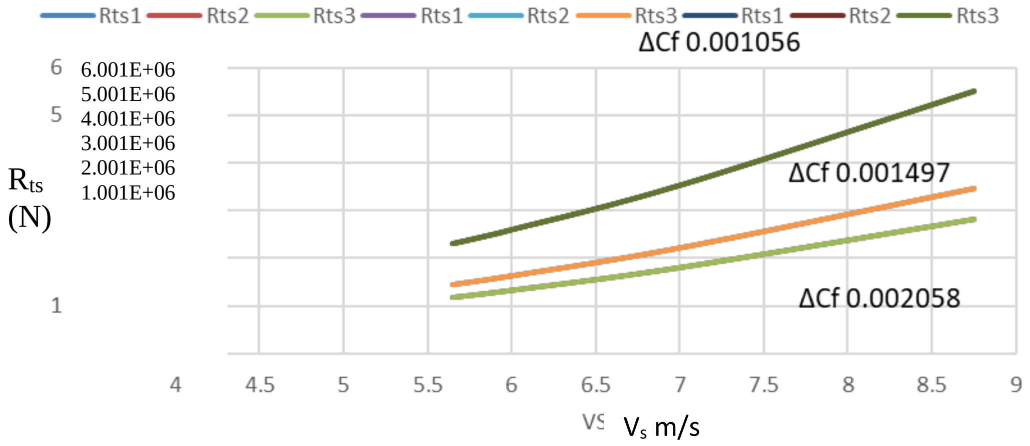

Fig. 11: Total resistance values plotted for different roughness conditions

The total resistance values were calculated for different fouling conditions and are plotted in Fig. 12 below.

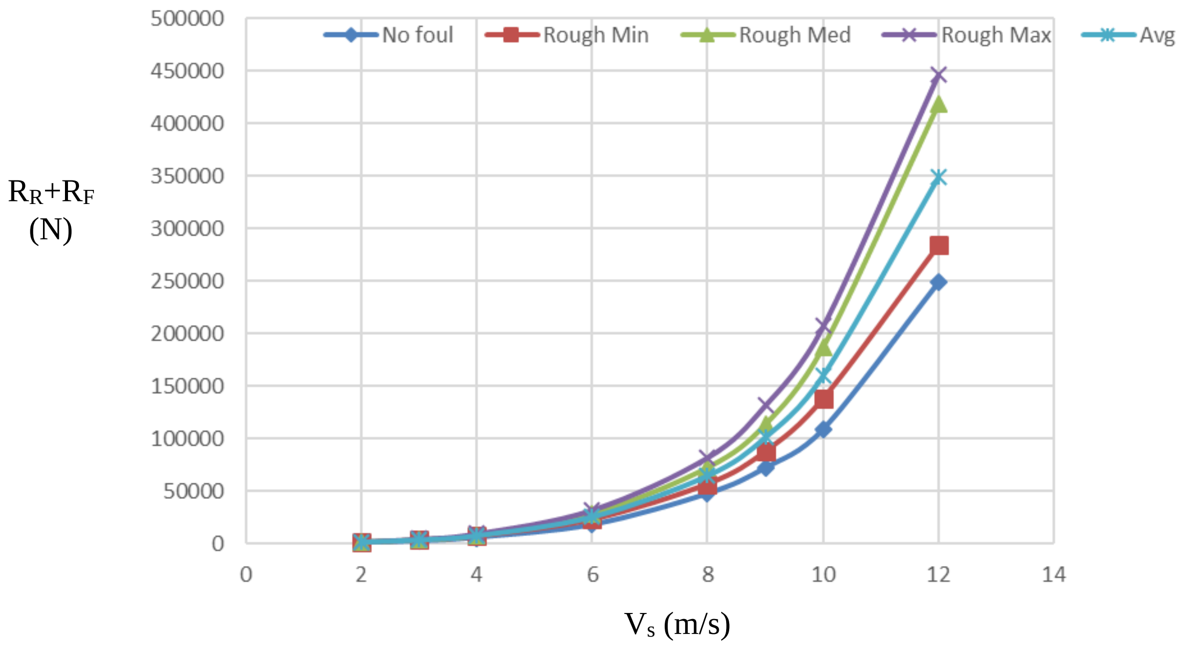

Fig 12: Calculated total resistance values for different fouling conditions

Calculate the same parameters by changing surface area (S) values and get a plot for other drafts. The calculations may be also extended to the ship hull with various fouling growth at different points.

6 SUMMARY

Here a methodology is proposed whereby it is possible to estimate ship resistance by incorporating different fouling conditions. Other fouling conditions were incorporated by estimating the resistance for a unit plank which was towed in the towing tank with different speeds. Change in resistance co-efficient due to the fouling was determined. Appropriate model speeds are arrived at matching the resistance components. The resistance calculated for unit planks can be extrapolated to full-scale ship. The result appears to be acceptable for researchers and analysts.

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