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INVESTIGATE THE DRAG RESISTANCE OF ANTIFOULING SELF-ADHESIVE FILM

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ABSTRACT

Fouling has been a common issue for ships as fouling drastically increases the surface roughness and ship resistance. The microfiber self-adhesive antifouling film has been claimed to effective up to 5 years and environmental friendly. However, there is lack of information about the drag characteristics of the antifouling material. Thus, this project is conducted based on an experimental study to determine the drag characteristics of the surface installed with microfiber self-adhesive antifouling film. The rotor apparatus is used to study the coefficient of friction of the microfiber surface. From the experimental results, a flat plate simulation using ANSYS-Fluent is conducted to further estimate the coefficient of friction up to Reynolds number of 10^9 and to estimate the total ship resistance for the Semi-SWATH (fast vessel) and KVLCC (slow trading ships). The results show that the percentage increase in total ship resistance for the KVLCC is about 80% which is more than the Semi-SWATH of 30%, as frictional resistance has high significance for slow trading ships. The speed drop experience by the ship model installed with the microfiber antifouling is 2 knots for the KVLCC and 1 knot for the Semi-SWATH when the power remained the same for both model.

Keywords : *Microfiber Antifouling; Frictional Resistance; Rotor Apparatus; Flat Plate Simulation*

1.0 INTRODUCTION

Marine fouling, which is the growth of marine organisms has been a common issue for the increase in drag resistance of the marine vessels and increase in fuel cost. Antifouling is the material or method used to prevent and reduce the growth of marine fouling.

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Resistance is the force opposing the motion of the body when the body moves through a medium. For ships, drag can be divided into two main types, which is the form drag and the viscous drag. Viscous drag depends on the thickness of the boundary layer, thereby highly affected by the roughness of the surface.

From the literature review conducted, it is found that there are no available data for the drag characteristics of the microfiber antifouling and it is difficult to measure the surface roughness of the microfiber material directly. The objectives of the research are to compare the drag characteristics of the microfiber material to a smooth surface and to estimate the ship resistance of the ship hull installed with the microfiber material.

This paper present the outcome from the study conducted which includes an experimental study using the rotor apparatus to determine the frictional resistance for the microfiber material and to conduct a flat plate simulation using ANSYS-Fluent to predict the ship resistance of the ship hull. Besides, this paper also presented the data for the drag characteristics of the microfiber surface, the estimation of speed drop and resistance performance for the ship hull if it is installed with microfiber anti-fouling material.

2.0 LITERATURE REVIEW

Fouling is the build-up of microorganisms on the surface and especially serious in the marine environment. Fouling contributes to the increase in drag, speed reduction and higher fuel consumptions Effects of fouling include the drastic increase of friction due to the influence of the fouling size [1] and fouling surface coverage on the boundary layer of the hull surface [3]. Fouling rate depends on the abundancy of microorganisms in various sea and the rate of activity of the vessel [4]. The accumulation of fouling causes speed loss, reduced manoeuvrability, increase in fuel consumption which causes rise in emission of air pollutants, increase in regularity of dry docking and translocation of invasive species across different marine organisms.

The early technique use for antifouling is by preventing fouling using toxic materials, such as mercury, arsenic and tributyltin (TBT), where TBT has been proven to contaminate the marine ecosystem and bring accumulative effects that can bring harm to human health. Self-polishing copolymer (SPC), more commonly known as the copper paint has been used for a long time and contains copper compounds, but constantly release copper compounds to the ecosystem [2]. Hence, with the rise of cleaner and safer environment, more effective and non-releasing antifouling were produced, such as the High-density Silicone Antifouling, that utilises the very smooth surface of silicone [5] and the self-adhesive microfiber antifouling surface that uses constant moving synthetic fibres to prevent growth of microorganisms [6].

Drag resistance or frictional resistance contributes to a high proportion of the total resistance of a ship, especially for slow trading vessels. Frictional resistance, also known as skin friction is affected by the surface roughness. Total resistance of a ship can be subdivided into two main types, which is frictional resistance and residual resistance.

Drag reduction has been observed for superhydrophobic surfaces that have the “lotus effect” such as self-cleaning properties and low wettability. The micro-structured surfaces capable of retaining air play the role of reducing resistance with the formation of an apparent slip length [7]. The microfiber surface also has the properties similar to the superhydrophobic surface and able to retain air when immersed in water.

Flow across the microfiber surface are visualized using high-speed digital holographic microscopy and it shows that the impact of roughness is localized on the momentum while the pillar effect of the micropillars affect the pressure field throughout the depth [8]. The flow rate of particles across the microfiber surface depend on the dimensions of the microfiber.

The rotor apparatus is a simple apparatus capable of measuring and comparing the frictional resistance of different surfaces. Although issues arise in the apparatus such as the end effects and doubt in the applicability of the logarithmic law on the 3D flow of the cylindrical block, previous studies have provided the method and prove to solve these issues such as the use of long and short rotor to remove the end effects.

Resistance of the ship can be calculated based on the ITTC equations, which is the ITTC-1957 Model Ship Correlation Line and ITTC-1978 equation. Two case studies, which is the model resistance for the Semi-SWATH [9] and the model resistance test for the KVLCC [10] is selected for this research. For the conversion of model resistance to ship resistance, ITTC method is used.

For the flat plate simulation using CFD, a simple 2D model is used neglecting wave generation and end effects to numerically calculate the frictional resistance of a surface with certain roughness [11]. Previous researches showed that the CFD results for flat plate agree with experimental results of a rotating disc given that fine meshing are used [12]. The k-ω model turbulence model was selected as it suitable for near wall modelling and applicable throughout the boundary layer. It is also capable of providing accurate results with fine meshing of the flat plate.

3.0 METHODOLOGY

The rotor apparatus experiment is conducted to obtain the coefficient of frictional resistance for the microfiber surface while the flat plate simulation is used to predict the coefficient of friction for higher Reynolds number and predict the total ship resistance of ship installed with the microfiber surface.

3.1 Rotor Apparatus Experiment

Figure 1 displays the experimental setup for the rotor apparatus. From the experiment, the speed of rotation and torque to rotate the rotor are recorded. The coefficient of friction for the surface can be calculated using the velocity loss theory.

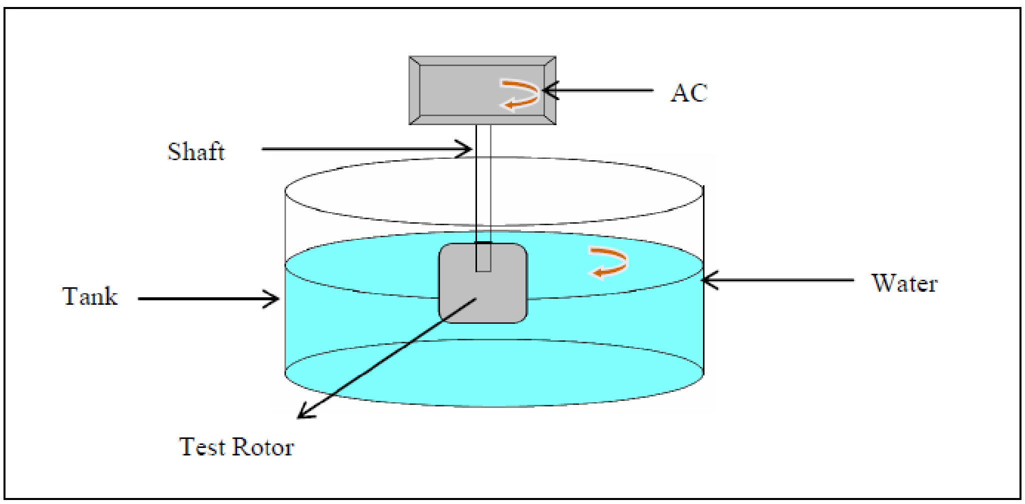

Figure 1: Experimental setup for rotor apparatus

The loss in velocity or the roughness function ΔU^+ is the difference between the frictional resistance of a rough surface and smooth surface, as shown in equation 1.

$$\Delta U^+ = \frac{\Delta U}{U_\tau} = \left(\sqrt{\frac{2}{C_f}}\right)_{smooth} - \left(\sqrt{\frac{2}{C_f}}\right)_{rough} \tag{1}$$

From the substitution for the equation for shear velocity and free stream velocity, the equation 2 is formed, whereby used for the calculation for the coefficient of friction for the surface.

$$c_f = \frac{900\Delta T}{\rho \pi^3 {r_1}^4 n^2 L} \tag{2}$$

3.1.1 Procedure of Rotor Apparatus

In the equation 2, the frictional drag coefficient can be calculate if the different of torque between long rotor and short rotor for the particular speed are known. Before the experiment start to collect the data, the long rotor which attached to the servomotor through shaft is turned by servomotor at slow speed for a few minutes to warm up the servomotor. All the apparatus is checked again for any problems or disturbance. Data is set to be taken for every 0.01 s for duration of roughly 30 s. After that, the servomotor is adjusted to the speed of 100 rpm. The speed obtained by the tachometer is compared with the speed display. If the speed tallies, then the data is started to record using DAQ system.

In this research, the speed of servomotor is increased from 100 rpm to 800 rpm with the increment of 100 rpm for each step. After the torque requires rotating the rotor at all particular speeds are measured, the experiment is repeated with short rotor. The torque requires rotating the short rotor at the similar rotation speed for long rotor are measured by torque meter.

3.2 Flat Plate Simulation

Flat plate simulation is used to estimate the surface roughness height for the microfiber antifouling. The k-omega turbulence model is used for the simulation and Figure 2 displays an example of the meshing for the flat plate of size 1.0m. An iterative process is used and curve fitting is done to obtain an equation for the estimation of surface roughness height. Then the equation is used to further estimate the coefficient of friction of the microfiber up to Reynolds number of 10^9.

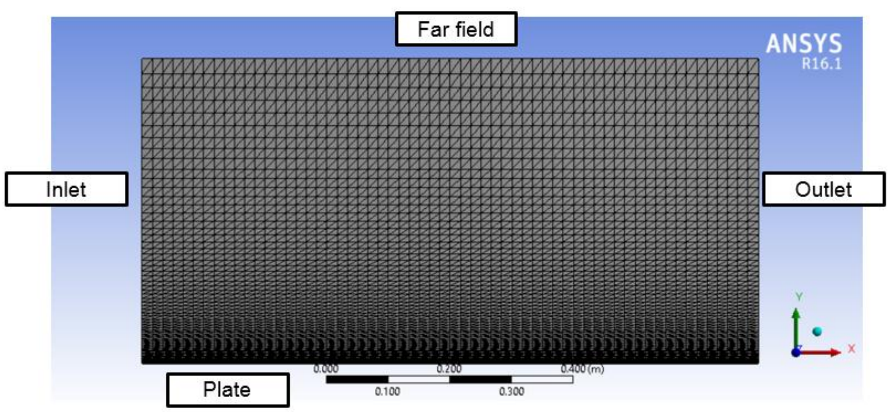

Figure 2: Meshing of flat plate (3721 nodes and 7200 elements)

The flat plate simulation is also used to predict the frictional resistance for the ship hull, where a convergence study is used to determine the number of divisions required for the flat plate with the size as the ship waterline length. The model resistance test data is converted to ship resistance by using the ITTC method. After the simulation results for the local coefficient of friction is obtained, the coefficient of friction is replaced and the total ship resistance for the ship hull installed with the microfiber antifouling is estimated. Equation 3 is used for the conversion of resistance to its non-dimensional terms and vice versa.

$$C = \frac{R}{\frac{1}{2}\rho S V^2} \tag{3}$$

The relationship of total resistance to frictional resistance and residual resistance is shown in equation 4 while the equation 5 is used for the determination of coefficient of frictional resistance using ITTC-1957 and equation 6 is used for the determination of coefficient of frictional resistance by using the drag force from simulation.

$$C_T = C_R + (1+k)C_F \tag{4}$$

$$C_F = \frac{0.075}{(\log_{10} Re - 2)^2} \tag{5}$$

$$C_{Fl} = \frac{F_D}{\frac{1}{2}\rho A V^2} \tag{6}$$

4.0 RESULTS AND DISCUSSION

Figure 3 displays the experimental results for the rotor apparatus comparing the coefficient of frictional resistance using the ITTC method, smooth rotor and rotor with antifouling surface. The C_f calculated via ITTC method is lower compared to the experimental results because it is an empirical formula that does not consider the effects of surface roughness.

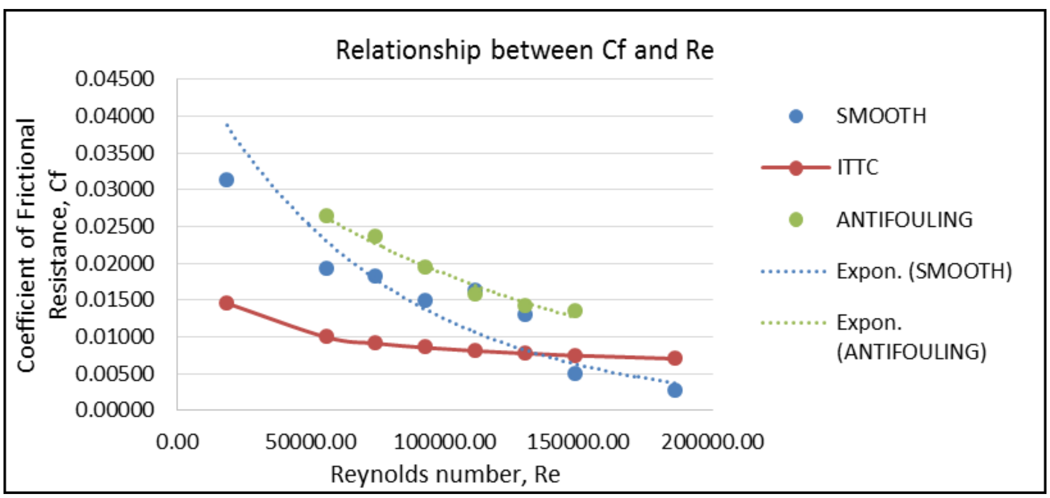

Figure 3: Experimental results for rotor apparatus

From the experimental results, the surface roughness for the microfiber antifouling estimated using the Flat Plate Simulation by ANSYS-Fluent. This is because the microfiber is not a solid surface making it difficult to measure the surface roughness directly. Figure 4 displays the relationship of C_f to Reynolds number for the simulation results using constant roughness height and varying roughness height. equation 7 is the equation for surface roughness obtained via curve fitting method.

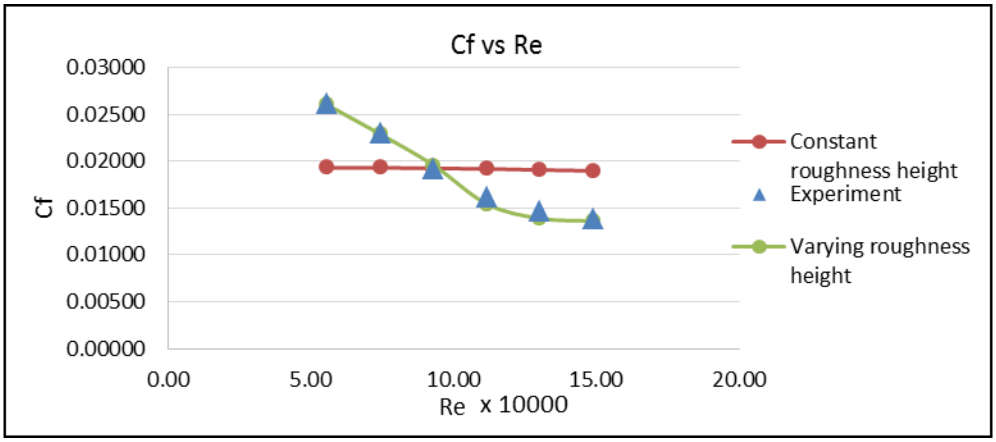

Figure 4: Comparison for simulation results using constant roughness height and varying roughness height.

$$Roughness\ height = \frac{0.003}{(\log_{10} Re - 4.5)^2} \tag{7}$$

From Table 1, as the speed of rotation increases, the surface roughness height decreases while Figure 4 shows that the surface roughness for the microfiber antifouling is not a constant value. Simulation using constant roughness height does not show a similar trend to the experimental results, while the simulation using the estimation of roughness height by using the equation 7 exhibits similar trend to the experimental results. Figure 5 displays the estimation of C_f by from simulation and shows similar trend to the ITTC results.

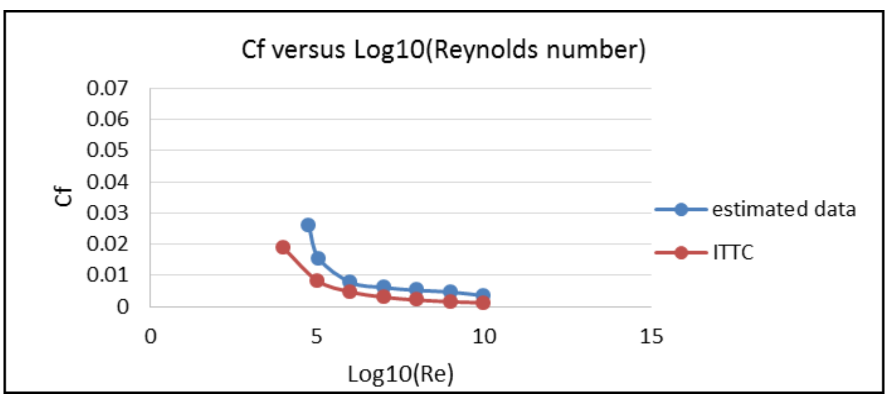

Figure 5: Estimation for C_f for higher Reynolds number

Figure 6 displays the relationship of total ship resistance to Reynolds number for the Semi-SWATH while Figure 7 shows the power to ship relationship. The simulation results for the total ship resistance installed with microfiber antifouling is 30% higher compared to the experimental results and the speed drop experiences is 1 knot.

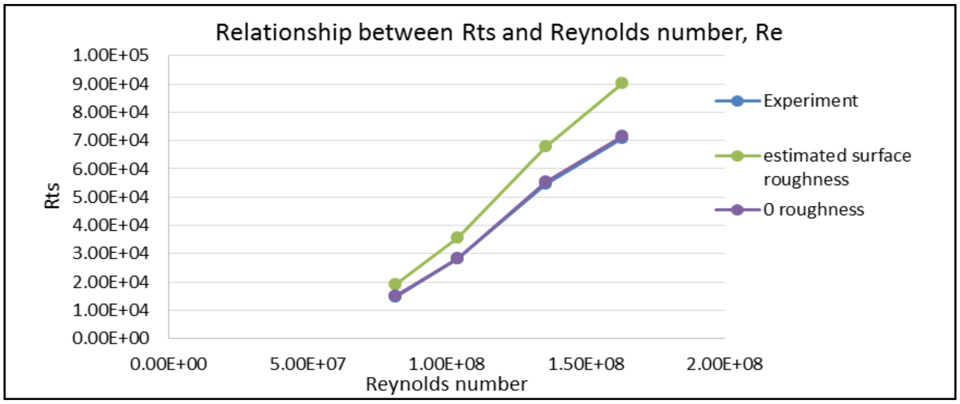

Figure 6: Total ship resistance for Semi-SWATH

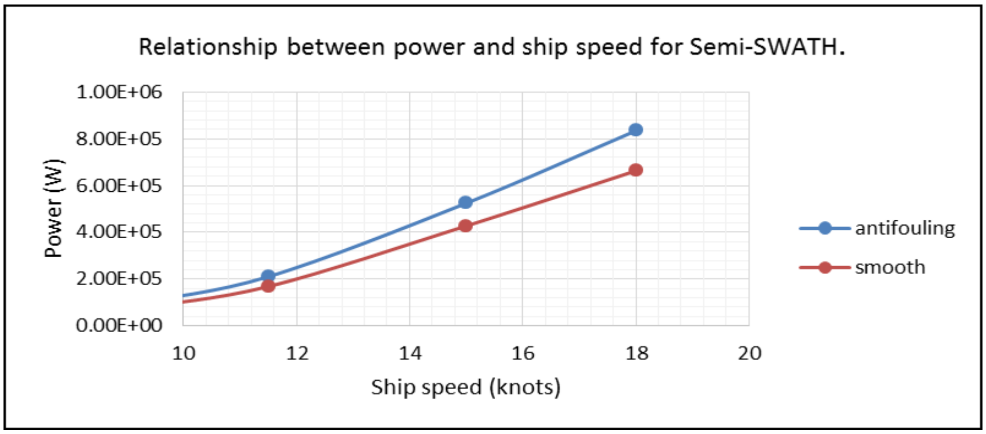

Figure 7: Relationship between power and ship speed for Semi-SWATH

Figure 8 displays the total ship resistance for the KVLCC while Figure 9 exhibits the relationship of power to ship speed for the KVLCC. The percentage increase in total ship resistance is 90% compared to the experimental results for the bare hull while the speed drop for the ship hull installed with antifouling is 2 knots.

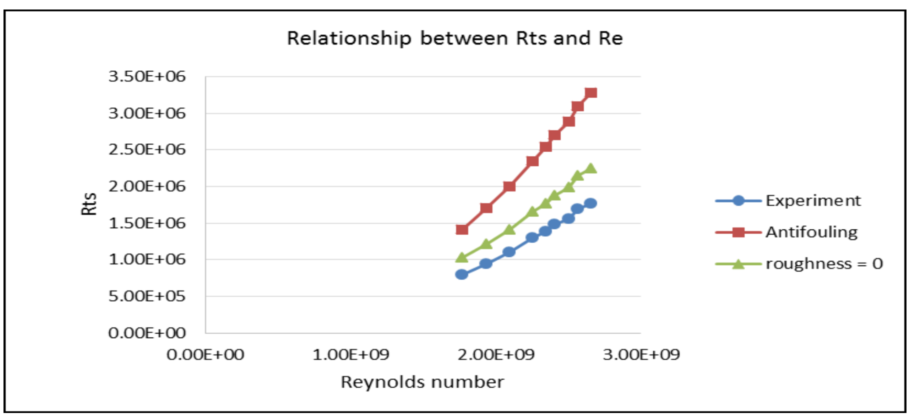

Figure 8: Total ship resistance for KVLCC

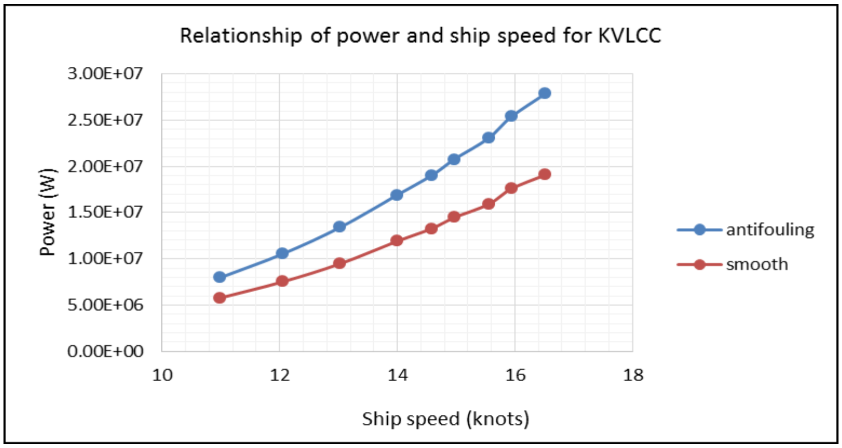

Figure 9: Relationship of power to ship speed for KVLCC

5.0 CONCLUSION

The objective of this research was achieved to compare the drag characteristics of the surface installed with antifouling self-adhesive film (microfiber surface) to smooth surface. The ship resistance for the ship hull installed with antifouling self-adhesive film was also estimated.

From the rotor experiment, the results obtained are consistent with the research conducted from previous studies. The average difference in coefficient of frictional resistance between the rotor installed with microfiber antifouling and the smooth rotor is about 30 percent.

For the KVLCC, the increase in frictional resistance due to the surface roughness of the hull results with an increase in total ship resistance of 80%, while for the Semi-SWATH, the increase in frictional resistance only increases the total ship resistance by 30%.

By comparison between the increase in frictional resistance due to fouling and the increase in resistance due to the antifouling material installed, it can be considered that the antifouling material as a solution to avoid fouling growth on hull surface, especially for fast vessels. This is because the increase in frictional resistance when the ship hull is fully covered with fouling is about 178% increase from the roughness height of 130μm, which occurs drastically, while the microfiber antifouling material has been claimed to have continuous antifouling effects up to 5 years.

NOMENCLATURE

ΔU^+	=	Loss in velocity/ Roughness function
U_τ	=	Shear velocity
$c_{f,} C_F$	=	Coefficient of frictional resistance
ΔT	=	Difference in torque
ρ	=	Density of medium
r_1	=	Radius of rotor
r_1	=	Speed of rotation
L	=	Length of rotor
C	=	Non-dimensional term of resistance
R	=	Resistance
S	=	Wetted surface area
V	=	Velocity
C_T	=	Coefficient of total resistance
C_R	=	Coefficient of residual resistance
$1 + k$	=	Form factor

Re	=	Reynolds number
C_{Fl}	=	Local coefficient of frictional resistance
F_D	=	Drag force

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