SKIN-FRICTION DRAG MEASUREMENT OVER A RECENTLY CLEANED AND PAINTED SHIP HULL UNDER STEADY CRUISING VIA IN-SITU LASER-BASED MEASUREMENT COUPLED WITH EMPIRICAL ESTIMATION.

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SUMMARY

A study in assessing the drag penalty due to hull roughness from a recently cleaned and painted ship hull is reported. The experiment is conducted on an operating ship (Roll-on/roll-off ferry) under steady cruising by measuring the velocity profile directly over the hull using a Laser Doppler Anemometer (LDA). The use of LDA allows a non-intrusive in-situ measurement without perturbing the flow over the ship hull. Here a window was installed on the underside of the hull, located approximately 25.5 m downstream of the bow of the ship during its annual dry-docking and hull cleaning. The in-situ measurement is also accompanied by surface scanning and a new empirical estimation technique that is based on average roughness height and effective slope. Initial results show that there is a substantial increase in skin-friction drag for a recently cleaned ship-hull compared to the hydrodynamically smooth surface.

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NOMENCLATURE

[Symbol]	[Definition] [(Unit)]
	Kinematic viscosity (N s m^{-2})
U	Mean velocity (m s^{-1})
U_τ	Skin friction velocity (m s^{-1})
U_∞	Free stream velocity (m s^{-1})
k	Roughness height (m)
k_s	Sand grain equivalent roughness (m)
k_a	Average roughness height (m)
L	Characteristic length scale (m)
δ	Boundary layer thickness (m)
z	Wall normal distance (m)
κ	Karman constant
A	wall intercept
Re	Reynolds number
C_f	Coefficient of friction
δ	Boundary layer thickness (m)
	Hama roughness function

1. INTRODUCTION

As one of the most important modes of transportation, the shipping industry has more than 100,000 ships operating worldwide and consumes around 200-300 million metrics of fuel annually [1-3]. The fuels are mostly used by the engine and propeller to overcome skin-friction drag that arises from the turbulent boundary layer formed on the ship hull. This skin friction drag is estimated to contribute up to 80%-90% of the total drag that is experienced by large ships, such as Very Large Crude Carrier (VLCC) or Large Bulk Carrier [4,5]. The already high contribution of skin friction drag is made worse by the existence of surface roughness [4,6]

Hull roughness is an important contributor to the energy usage in the shipping industry. They generally in the form of surface imperfections due to mechanical defect or biofoulings [6-9]. A ship hull can often seem clean and relatively smooth, when it has just recently experienced dry-dock, where the hull is cleaned and protected with anti-corrosion and anti-fouling paints. However, a closer inspection will reveal that the hull surface experience "orange peel" roughness pattern that is above the ideal hydrodynamically smooth state. From the fluid flow point of view, such surface roughness becomes appreciable in term of viscous length scales. Viscous length scale can be defined as ν/U_τ where ν is kinematic viscosity and U_τ is skin friction velocity. A surface is considered smooth with no extra drag penalty when the viscous scaled roughness height $k^+ < 5$, where $k^+ = k\, U_\tau/\nu$ (here k is roughness

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height). For a Large Bulk Carrier moving at cruise speed and with a high U_τ value, the maximum allowed physical roughness height is around m. Such height is smaller than the average "orange-peel" pattern which typically ranging from 0.1 – 0.5 mm. Hence even a recently cleaned and painted ship hull may already experience a significant elevated skin-friction drag.

Due to hull roughness importance in shipping industry, particularly its impact on energy usage, there has been plenty of significant efforts in estimating the full-scale ship drag due to hull imperfections. Currently, the most common method in estimating ship drag penalty due to roughness is via laboratory experiment which involves roughness scanning and replication [6-11]. The replicated surface roughness is then laid inside water tunnel, wind tunnel, or towing tank where the flow over the roughness is measured via hot-wire anemometer, Particle Image Velocimetry (PIV), Laser Doppler Anemometer (LDA), or force balance. The challenge in using such methods however, is the cost (both in laboratory facilities and time). Furthermore, laboratory experiment is generally represents only a small part of the ship hull, due to the limitation in scanning area [11]. Hence the laboratory experiment may not be able to replicate the actual turbulent flow over a ship hull and capture the flow dynamics fully.

To overcome the laboratory experiment issues, it is desirable to directly measure the flow over the ship hull. This can be done by using manometer and Pitot tube that is attached to a traversing system under the hull of moving ships [12-14]. This would allow one to measure the hull mean velocity and estimate its skin friction drag. The issue with this method however, is the lack of high order velocity statistics. Moreover, the Pitot tube is also prone to blockage by sea creatures and other solid materials. To have a more reliable data and higher velocity statistics, it is desirable to use a non-intrusive high-speed measurement method such as Particle Image Velocimetry (PIV) or Laser Doppler Anemometer (LDA).

A more desirable technique in estimating hull roughness (particularly for the shipping industry) is to bypass any experiment altogether and to use an accurate empirical estimation technique. Particularly a method where one could predict drag penalty from an easily obtained hull roughness profile. In the last three decades, there have been many efforts by the industry to come up with a form of empirical estimation [15]. However, many of these estimations are unable to capture the dynamic of the flow fully. Particularly because they do not consider many of the critical roughness properties such as solidity, effective slope, skewness, average roughness height, etc. Moreover, the lack of direct flow measurement from operating ships that can be used as a comparison/basis with the available empirical estimation is complicating the issue further.

To answer those challenges, in this study we report an initial data of LDA experiment from a recently cleaned and painted ship hull under cruising conditions. The experiment data is also complemented with an empirical estimation from the same ship hull surface that is obtained from imprint and surface scanning. The empirical estimation is based on the recent publication of Chan et al [14]. Note that this report is based on and also serves as an extension of our recent conference publication [16] and [17] that was presented at the RINA ICSOT (Jakarta, 14-15 November 2017) and ISME (Tokyo, 15-19 October 2017)

2. EXPERIMENT

2.1 EXPERIMENT DETAILS AND SET-UP

The experiment was conducted on an operating Roll-on/off ferry Dharma Kencana IX, owned by PT Dharma Lautan Utama. The ferry has a length of 70 with a cruise velocity of 9-10 knots (4.5-5 m/s). The ship operates in Sunda-strait Indonesia, serving Merak-Bakauheni. To house the LDA system and computer controlled traversing rail, a window with a watertight enclosure is constructed between the double bottom hulls. The window is located approximately 25.5 m downstream of the bow of the ship during its annual drydocking. The window has a diameter of 300 mm and thickness of 23.52 mm. It is made of two tempered glass discs laminated with Polyvinyl butyral/PVB. Figure 1 illustrates the experiment set up and figure 2 shows the LDA arrangement inside the watertight enclosure.

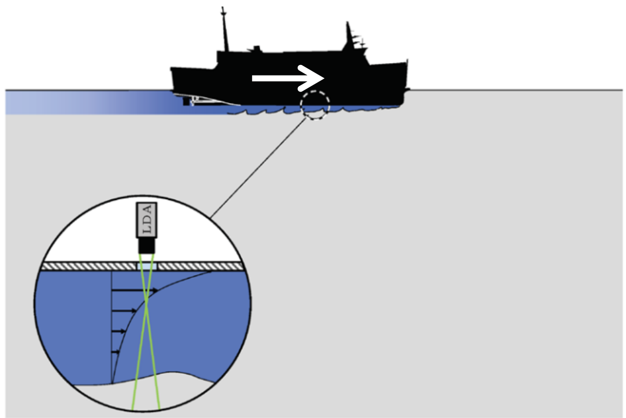

Figure 1: Illustration of the LDA set-up that measure the mean velocity profile inside the turbulent boundary layer that develop over ship's hull.

The LDA system used is a two-component Laser Doppler Anemometer from Dantec (FlowExplorer). The LDA has two cross beams at the wavelength range of 650 – 670 nm (red) and 770 – 810 nm (near infra-red). The measurement is conducted when the ship reaches its operating cruise speed and maintaining a constant free stream velocity. Note that here we rely solely on the natural small particle as seeding. We do not introduce artificial seeding in order not to contaminate the sea and endanger the local marine life.

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Figure 2: LDA system set up inside the water tight enclosure.

2.2 HULL ROUGHNESS CONDITION

To complement the LDA experiment, we also record the ship's hull roughness profile by using silicone rubber imprint and laser triangulation sensor (Keyence™ LK-031). Figure 3 shows the resulting surface roughness scan. It reveals that the hull has an "Orange-peel" type finish quality with roughness height ranging from 0.1-0.5 mm. Details of the roughness parameter are tabulated in table 1.

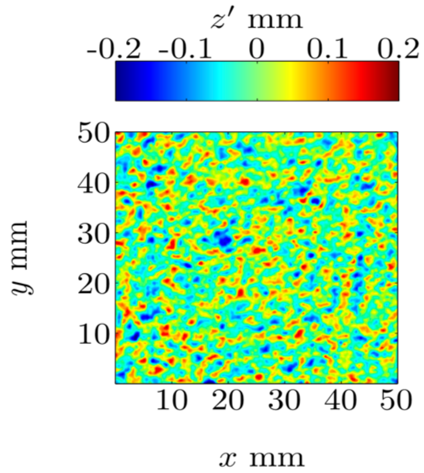

Figure 3 : Surface roughness scan result

Parameter	Value	Units	Equation
k_a	0.0413	mm	$\overline{\lvert z' \rvert}$
k_{rms}	0.0519	mm	$\sqrt{\overline{z'^2}}$
k_p	0.4791	mm	$\max z' - \min z'$
k_{sk}	0.0868	-	$\overline{z'^3}/k_{rms}^3$
k_{ku}	3.0712	-	$\overline{z'^4}/k_{rms}^4$
ES_x	0.0890	-	$\overline{\lvert dz'/dx \rvert}$

Table 1: Surface roughness parameters

From our private discussions with antifouling representatives, this type of roughness pattern is very common in many recently dry-docked ships. Moreover, a more severe roughness pattern is also commonly encountered in many recently cleaned and painted ships. The roughness generally arises from repeated cleaning process, such as scrapping, water blasting, and sandblasting. The inconsistencies of hull painting method are also contributing to the hull surface imperfection.

2.3 EXPERIMENT RESULTS

Figure 4 shows the resulting mean velocity profile for the ship board experiment (grey circle) and smooth wall reference (open circle). Here we use Clauser method [20, 21] to estimate the skin friction drag over the smooth wall:

$$\frac{U}{U_\tau} = \frac{1}{\kappa} log\left(\frac{z\,U_\tau}{\nu}\right) + A \qquad (1)$$

where κ = 0.384 is the Karman constant, A = 4.2 is the wall intercept, and ν is kinematic viscosity of water. For the rough surface (from the shipboard experiment) we use modified Clauser method [20, 21]:

$$\frac{U}{U_\tau} = \frac{1}{\kappa} log\left(\frac{z\,U_\tau}{\nu}\right) + A - \Delta\left(\frac{U}{U_\tau}\right) \qquad (2)$$

Here the entire profile is shifted downwards by $\Delta(U/U_\tau)$ or ΔU^+ which represents the increase in drag penalty.

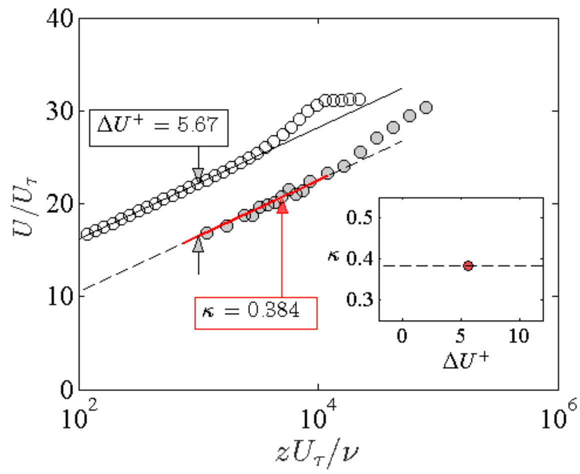

Figure 3: Mean velocity profile of smooth wall (from Marusic et al [19]), marked with open circles; and the rough ship hull , marked with grey circles. The inset figure shows the value of Hama roughness function against κ.

From the mean velocity profile of turbulent boundary layer over the smooth and rough wall, we can calculate the local skin friction coefficient C_f as a function of Reynolds number via mean momentum integral equation. The method is similar to that of Monty et al [11] and Granville [22]. Figure 4 shows the estimated average skin friction

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coefficient for the smooth surface (open circles) and the rough hull (grey circles) for ranges of Reynolds number,

$$Re_x = U_\infty\, L/\nu \ . \qquad (3)$$

Where U_∞ is the ship free stream velocity/cruising velocity, L is characteristic length scale. The dashed vertical black line shows the optical access location at 25.5 downstream at 5 m/s (ship's cruise speed).

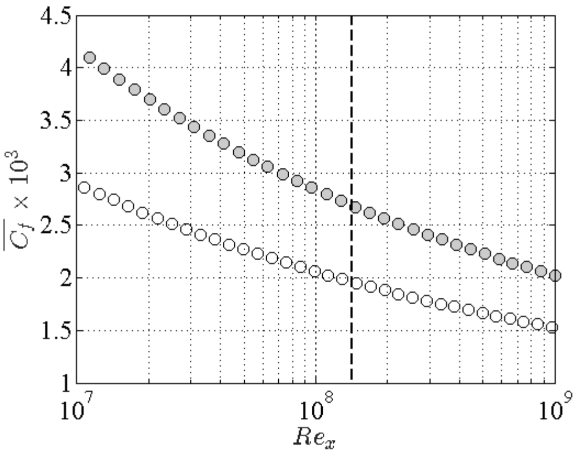

Figure 4: Average skin friction coefficient against Reynolds number for the (open circles) smooth surface and (grey circles) for the rough surface from LDA. The vertical dashed black line is the Reynolds number of the ship at downstream location of 25.5 m (optical access location) and cruise speed of 5 m/s

From this plot, we can see that the for the rough surface the coefficient of friction is 2.69 x 10^{-3} (at the cross of vertical dashed line and grey circle) while for the smooth wall the C_f is 1.96 x 10^{-3} (at the cross of vertical dashed line and open circle). The differences between the smooth and rough wall C_f is around 37%. This calculation indicates that even a freshly cleaned and painted ship hull, may already experience a 37% increase of drag penalty.

3. EMPIRICAL ESTIMATION OF HULL ROUGHNESS

Hull roughness empirical estimation method is a much sought-after technique by the shipping industry. It allows one to predict the increase of dag penalty due to hull imperfections. For a ship operator, a relatively accurate drag penalty estimation would lead to a more informed dry docking and cleaning schedule, and would result in a more economical and optimum ship operation.

A recent report by Chan et al [23] shows that one would need a minimum of two easily obtained roughness parameters, average roughness height k_a and effective slope ES_x, to estimate the increase in drag penalty:

$$\Delta\left(\frac{U}{U_\tau}\right) = \frac{1}{\kappa} log\left(\frac{k_a\, U_\tau}{\nu}\right) + \beta \log ES_x + \gamma \ . \qquad (4)$$

Where β and γ are constants with value 1.12 and 1.47 respectively.

Here we use equation 4 to estimate the drag penalty of the recently cleaned Dharma Kencana IX and to compare it with the in-situ LDA results. The required average roughness height k_a and effective slope ES_x in equation 4 is taken from surface scan results (see table 1). By combining it with the mean momentum integral formulation [11, 22], one could estimate the average skin friction coefficient.

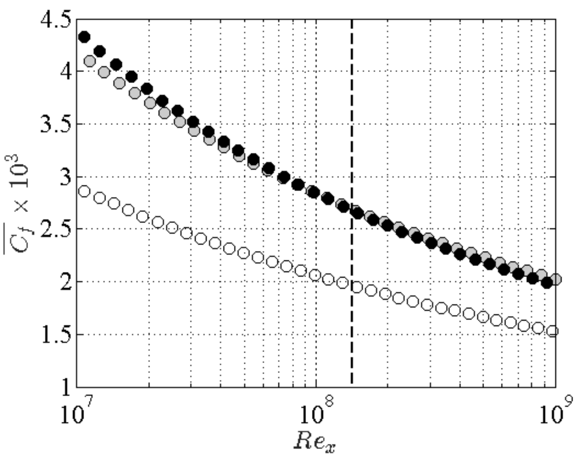

Figure 5: Average skin friction coefficient against Reynolds number for the (open circles) smooth surface, (grey circles) for the rough surface from LDA, and (black circle) empirical estimation. The vertical dashed black line is the Reynolds number of the ship at downstream location of 25.5 m (optical access location) and cruise speed of 5 m/s

Figure 5 shows a similar plot with figure 4, with the addition of empirical estimation calculation formulated by Chan et al [23]. The data shows a close approximation of C_f value between the LDA and empirical estimation. Note that at $Re_x < 6 \times 10^7$ the empirical estimation is over estimate the LDA data, while at $Re_x < 6 \times 10^8$ the empirical estimation is underestimate the LDA result, albeit in small percentage difference. Note that at the Re_x where the optical access is located during cruise speed (at the cross of vertical dashed line with open circle and closed circle), the C_f between LDA and empirical estimation is almost identical. We believe it is purely coincidental.

Although the proposed estimation technique seems to work relatively well with this type of roughness, the methods still need further investigation for other forms of roughness and parameters, such as sparseness, wavelength, etc. Further laboratory and computational fluid dynamics studies are needed to confirm the empirical estimation's robustness.

4. CONCLUSIONS

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An investigation that looking into the effect of hull roughness from a recently cleaned and painted ship is reported. Here we conducted two types of investigation, the first is an in-situ measurement where we measured the mean velocity profile of an operating ship using LDA and the second is an empirical estimation that utilises two roughness parameters (average roughness height k_a and effective slope ES_x). The outcome shows that both methods agree well with each other, showing a drag penalty increase of 37%. The results show that even a "clean" hull may already have a substantial drag increase. Even though the empirical estimation agrees well with the in situ experiment the result should be treated as a preliminary approximation. Additional investigations into this new empirical estimation are needed, particularly for other type of roughness with different parameters.

5. ACKNOWLEDGEMENTS

The authors would like to thank the Australian Research Council (ARC) and the Newton Fund from the British Council for financial support.

6. REFERENCES

1. CORBETT, J. J., WINEBRAKE, J. J., GREEN, E. H., KASIBHATLA, P., ERYING, V., LAUER, A., Mortality from ship emissions: A global assessment. *Environ. Sci. Technol.,* 41(24) : 8512 – 8518, 2007.

2. WINEBRAKE, J. J., CORBETT, J. J., GREEN, E. H., LAUER, A., ERYING, V., Mitigating the health impacts of pollution from oceangoing shipping : An assessment of low-sulfur fuel mandates. *Environ. Sci. Technol.* 43 (13) 4776 – 4782, 2009.

3. ERYING, V., ISAKSEN, I., BEMSTEN, T., COLLINS, W. J., CORBETT, J. J., ENDERSEN, O., GRAINGER, R. G., MOLDAVONA, J., SCHLAGER, H., STEVENSON, D. S., Transport impacts on atmosphere and climate: Shipping. *Atmos. Environ*., 44(37):4735–4771, 2010.

4. LACKENBY, H., 'Resistance of Ships, With Special Reference to Skin Friction and Hull Surface Condition. Proceedings of the Institution of Mechanical Engineers, 176 :981–1014, 1962.

5. KODAMA, Y., KAKUGAWA, A., TAKAHASHI, T., and KAWASHIMA, H,. "Experimental study on microbubbles and their applicability to ships for skin friction reduction", Int. J. Heat and Fluid Flow, Vol.21, pp.582–588, 2000.

6. GRIGSON, C. Drag losses of new ships caused by hull finish. J. Ship. Res 36(2):182–196, 1992

7. SCHULTZ, M. P., (2004) Frictional resistance of antifouling coating systems. *J. Fluids Eng.* 126(1039), 2004.

8. SCHULTZ, M. P., Effects of coating roughness and biofouling on ship resistance and powering. *Biofouling* 23(5-6):331–341, 2007

9. SCHULTZ, M. P., BENDICK, J. A., HOLM, E. R. & HERTEL, W. M., Economic impact of biofouling on a naval surface ship. *Biofouling* 27: 87–98, 2011.

10. LINDHODLT, A., DAM-JOHANSEN, K., OLSEN, S. M., YEBRA, D. M., KIIL, S., 2015. Effects of biofouling development on drag forces of hull coatings for ocean-going ships: a review. *J. Coat. Technol. Res*. 12(3) 415-444

11. MONTY, J. P., DOGAN, E., HANSON, R., SCARDINO, A. J., GANAPATHISUBRAMANI, B., HUTCHINS, N., An assessment of the ship drag penalty arising from light calcareous tubeworm fouling. *Biofouling*, 32(4): 451-64, 2016.

12. LIVINGSTON SMITH, S, BSRA resistance experiments on the LUCY ASHTON – Part IV, Miscellaneous investigations and general appraisal. *Trans Rina.* 97(4): 525-561, 1955

13. TANIGUCHI, K., FUJITA, T., Comparison of velocity distribution in the boundary layer between ship and model. J of the Soc of Naval Arch of Japan. 127:13-21, 1970

14. LEWTHWAITE. J.C, MOLLAND. A. F, THOMAS.K. W. An investigation into the variation of ship skin frictional resistance with fouling. *Trans RINA*. 127:269 – 284, 1984

15 HUTCHINS, N., MONTY, J. P., NUGROHO, B., GANAPATHISUBRAMANI, B., UTAMA, I. K. A. P., (2016) Turbulent boundary layers developing over rough surfaces: from the laboratory to full-scale system. 20th Australasian Fluid Mechanics Conference. Perth, Australia.

16 CHAN, L., MACDONALD, M., CHUNG, D., HUTCHINS, N., OOI, A., "A systematic investigation of roughness height and wavelength in turbulent pipe flow in the transitionally rough regime". J. Fluid Mech, vol.771, pp. 743–777, 2015

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17 B. NUGROHO, R. BAIDYA, M. N. NURROHMAN, A. K. YUSIM, F. A. PRASETYO, M. YUSUF, I. K. SUASTIKA, I. K. A. P. UTAMA, J. P. MONTY, N. HUTCHINS, B. GANAPTHISUBRAMANI (2017) *In-situ turbulent boundary layer measurements over freshly cleaned ship-hull under steady cruising*. Royal Institution of Naval Architects (RINA) Conference, International Conference on Ship and Offshore Technology (ICSOT). Jakarta, Indonesia.

18 I. K. A. P. UTAMA, B. NUGROHO, C. CHIN, M. L. HAKIM, F. A. PRASETYO, M. YUSUF, I. K. SUASTIKA, J. P. MONTY, N. HUTCHINS, B. GANAPTHISUBRAMANI (2017) *A study of skin friction drag from realistic roughness of a freshly cleaned and painted ship hull*. International Symposium on Marine Engineering (ISME). Tokyo, Japan.

19. MARUSIC, I., CHAUHAN, K. A., KULANDAIVELU, V., HUTCHINS, N., 2015. Evolution of zero-pressure-gradient boundary layers from different tripping conditions. *J. Fluid Mech*, 783, 379-411

20. CLAUSER, F. H., 1954. Turbulent boundary layers in adverse pressure gradients. *J. Aeronaut Sci*. 21, 91–108.

21. CLAUSER, F. H., 1956. The turbulent boundary layers. *Adv. Appl. Mech*. 4,1–151.

22. GRANVILLE, P.S. The frictional resistance and turbulent boundary layer of rough surfaces. J. Ship. Res 2: 52–74, 1958.

23. CHAN, L., MACDONALD, M., CHUNG, D., HUTCHINS, N., OOI, A., 2015 A systematic investigation of roughness height and wavelength in turbulent pipe flow in the transitionally rough regime. J. Fluid Mech, vol.771, pp. 743–777,

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