INTERNATIONAL COLLABORATIVE WORK TO IMPROVE RESEARCH QUALITY AND ENHANCE ACADEMIC ACHIEVEMENT

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SUMMARY

A large scale joint research project is underway, with the aim of improving the efficiency of ship operations by providing a methodology and technology that can accurately quantify the emission and fuel usage penalty due to bio-fouling of the hull. The research involves six different institutions from four countries (Australia, Denmark, Indonesia, and UK) bringing together universities, a passenger ship company, a manufacturer of anti-fouling coatings, and the Indonesian Classification Society. Here the importance of individual role and contributions from each institution are discussed. The six participants in general represent academic, industrial, and an independent party that promote of safety of life, property and the environment as well as to support policy makers, each with different objectives and interests that are interconnected. This paper will explains the importance of collaboration and satisfying individual objectives from each field in order to achieve the collaborative overarching aim

1. INTRODUCTION

In the last decade the issue of global warming and the energy crisis have prompted efforts to find methods of reducing energy consumption for shipping industries (Davies, 2006; Longva et al., 2010). Countries such as Australia, Indonesia, and the United Kingdom (UK) all rely heavily on long-haul shipping transportation due to their unique geographical location and condition. Australia is a large continent, with diverse population centres, that is geographically isolated from major trading partners. In addition, the strong resource sector puts strong demands on export bulk shipping. Indonesia is an archipelago of 17,499 islands with a large population (250,000,000). The country is heavily reliant on ships and ferries to transport people and goods between islands. With an average of 4-5% economic growth (Tabor, 2015), Indonesia's dependence on naval transport will rise significantly. UK is geographically separated from the main European continent by the English Channel and the North Sea. The country is also heavily reliant on naval transport to import and export goods. Faced with the ever increasing pressure to reduce the environmental, energy, and economic footprint, it is important for countries such as Australia, Indonesia, and the UK to address energy issues in the shipping industry.

Hull roughness is an important, but largely unquantifiable contributor to the overall energy expenditure and emissions from the worlds shipping fleet. The hull of a ship has underlying roughness due to manufacturing imperfections (weld seems, panel misalignment etc), coatings (topology resulting from application of corrosion and foul-resist coatings) and most importantly from Biofouling: the settlement of marine organisms on to the ship hull. Many studies, particularly by Schultz (2004, 2007, 2011) have shown that biofoulings have significant contribution to the increase of ship's drag, with a large economic penalty. Despite the severity of this issue, currently there are no reliable methods to enable ship operators to quantify the drag penalty due to hull roughness for an in-service vessel.

Considering the global scale of the challenge, an international research collaboration that involves six institutions from four different countries has been formed, namely: Institute of Technology Sepuluh Nopember, Biro Klasifikasi Indonesia (Indonesian classification society), and Dharma Lautan Utama passenger ship Company from Indonesia; the University of Melbourne from Australia, , the University of Southampton from the United Kingdom (UK); and Hempel A/S from Denmark.

The main objective and overarching aim of the collaborative research is to understand the skin friction drag on ships hulls due to biofoulings and to improve the efficiency of ship operations by providing a methodology and technology that can accurately quantify the emission and fuel usage penalty. This can be obtained through detailed under-water image-based surface scanning techniques, coupled with in-situ laser-based measurements of the water flow over the hull of the ship. These methods will provide direct data on the increase in drag experienced by the ship under different fouling conditions. The two shipboard experiments are

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complemented and validated by detailed laboratory experiments. The outcome of the investigation will permit the maritime industry and policy makers to make more informed decisions in terms of operations at operational or regulatory level. The research collaboration also allows the academic institutions to improve research quality and enhance academic achievement and student outcomes.

To accomplish the main objective, the six different institutions need to work and collaborate closely, particularly because each of them has different expertise and specific roles that complement each other. In general the six participants can be divided into *three major fields*, namely: academic, industry, and classification society to support policy maker. Each of these fields has different interests and expected outcomes, however they form the base of the overall main objective for the research collaboration. In this report we will discuss the motives and details of the joint research, the role of each institution, the expected outcome from individual fields, and how these individual objectives are correlated and satisfied to achieve the overall goal

2. MOTIVE OF FORMING RESEARCH COLLABORATION

The proposed collaborative research project requires a large quantity of facilities, funding, and personnel due to its scale. To the best of author's knowledge there have been very few attempts at this type of investigation. However, one such study is by Lewthwaite et al. (1984). Their research involved three different institutions, namely: a university, a government research agency, and a marine company. Hence, this type of research collaboration is a very challenging venture to be performed individually. Therefore it is desirable to share the research burden with various institutions that have similar aspiration (Katz and Martin, 1997). Studies regarding research collaboration show that scientific endeavour is becoming more collaborative, particularly between different organisations, both within a country or internationally (Subramanyam, 1982; Melin and Persson, 1996). The same studies also show that collaboration improves scientists' visibility and productivity.

Although collaboration between academic institutions is very common, the amount of collaboration between academic institutions and industry or government bodies is comparably lower. According to Bruneel et al (2010) there are several barriers that impact research collaboration between the different fields of academia, industry, and policy makers. Particularly in the form of differing methods of administering private and public knowledge (Bruneel et al, 2010; Dasgupta and David, 1994). At its core, scientists in academic institutions are motivated by academic excellence and education while industry firms are driven by economic value derived from competitive advantage (Dasgupta and David, 1994).

Despite these challenges, Bruneel et al (2010) reveal that inter-organisational trust is needed to lower barriers between academic institutions and industry. They even go further by implying that informal exchange and interaction should be attempted to build good rapport. We believe that a similar method can be applied when collaborating with government institutions. For this research collaboration, it is clear that close cooperation and communication is needed. Particularly when the possible benefit for all parties involved clearly outweighs any drawbacks.

3. THE COLLABORATIVE RESEARCH METHODOLOGY

The research methodology can be subdivided into four research strands (or work packages), which will meet the overall aim of the project.

3.1 Research Strand 1: Laser Doppler Anemometer Measurement (LDA).

For this research strand we intend to perform direct in-situ measurements using LDA in the boundary layer formed over a ship's hull under sailing conditions, to monitor the influence of the accumulation of bio-fouling on the skin friction drag (see Buchhave et al 1979 and Tropea 1995 for further reading regarding LDA). Such direct investigations have been very rarely performed, but are critical if we are to be able to ascribe a precise figure to the economic impact of bio-fouling to ship operations. One notable attempt at a similar study is that by Lewthwaite et al. (1984), however they used pitot tubes instead of LDA, and did not obtain a record of the hull state.

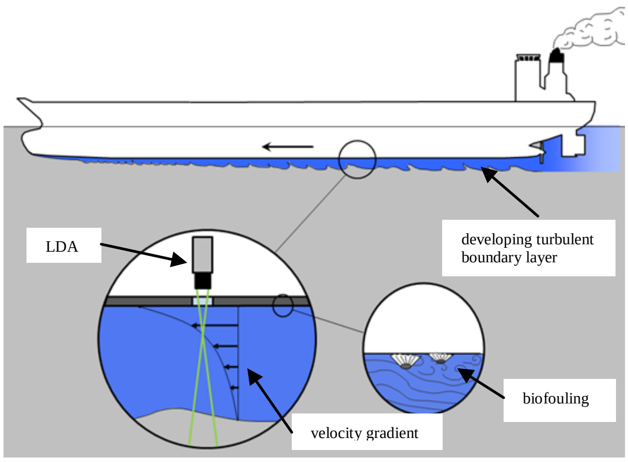

Figure 1 : Illustration of the LDA with turbulent boundary layer and surface roughness in ships

Here a small window is placed in the hull of an Indonesian operating ship during dry-docking, at which point the ship is also cleaned and recoated with anti-fouling products. The LDA is installed in the hull of the ship to measure the velocity gradient in the turbulent

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boundary layer formed over the ship's hull as it sails (see figure 1). The LDA can obtain an in-situ fluctuating velocity signal across some traversable distance from close to the hull surface, to at least the end of the logarithmic region. From the velocity gradient we can directly calculate the percentage increase in skin friction drag. This will be monitored (along with other key data - GPS coordinates, velocity, sea-state, fuel usage, draft etc) during the course of the inter dry-docking period (1 - 3 years depending on funding level).

3.2 Research Strand 2: Image Based Surface Scanner

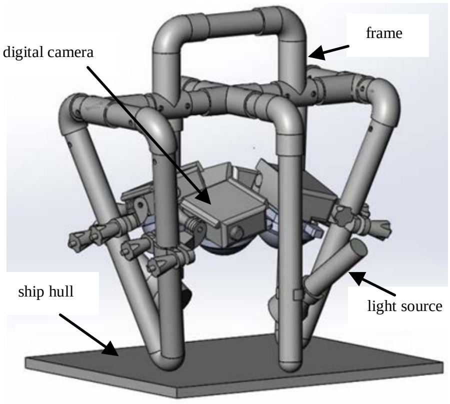

Figure 2 : Surface scanner

One thing that lacking from Lewthwaite et al.'s (1984) report is the absence of the hull-condition record. The unavailability of this data prevented them from quantifying the effect of biofouling topography to the skin friction drag in more detail. To avoid similar drawbacks here we use an image-based surface scanner to monitor the state of the hull surface finish. This activity starts during dry-docking, when the quality of the surface finish from the spraying and cleaning process will be quantified and will continue through regular (approx monthly) dive inspections until the next dry-docking.

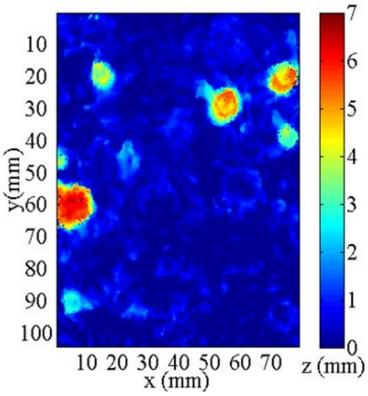

Figure 3: Digitally reconstructed biofouling from surface scanner

Figure 2 shows the proposed surface scanner. It is made of four digital underwater cameras attached frame. The previously calibrated four cameras will simultaneously take a photo of the hull surface and then digitally reconstruct (see figure 3) the surface topography. The scanning of the bio-fouled hull is performed alongside the measurement with the LDA system, which allows a direct comparison between the physical dimension of the bio-fouling and its effect on the ship skin-friction drag. The scanned data will later be used in the third and fourth strands of this research.

3.3 Research Strand 3: Data Correlation

Here the LDA measured drag, and ship-board data such as GPS coordinates, velocity, sea-state, fuel usage, draft etc are mined and correlated with the surface scan data. This will allow us to produce a full scale prediction of drag penalty and in an attempt to produce a workable correlation/equation that will ultimately enable the hull fouling penalty to be calculated directly from surface scan information.

3.4 Research Strand 4: Aerodynamics Testing

For this strand we intend to investigate the effect of a realistic bio-fouling on the turbulent boundary layer under more controlled laboratory conditions to validate the efficacy of the proposed LDA gradient-based technique. The LDA method is novel and unproven. There have been many studies that investigate the effect of bio-fouling on turbulent boundary layers. Some of these studies involve an actual bio-fouling that has been grown in their natural habitat and then removed to a laboratory for experiment (Walker et al (2013), Schultz and Swain (1999)). However, this technique is relatively difficult to perform due to the challenges in preserving them for lab experiments, particularly the effect of change in the natural environment (from ocean to lab water tank). One method to avoid this challenge is by realistically replicating the bio-fouling through casting, machining, rapid-prototyping or combinations of the three. The advantages of replicated geometries are that it is not necessary to introduce fouling into sensitive experimental facilities and the surfaces can be scaled for testing at different conditions or in the case of bio-fouled surfaces, testing using fluids other than seawater (i.e fresh water or air).

Using the digitally reconstructed and scaled biofouling data from the surface scanner (from strand 2), a detailed master model is manufactured and replicated using a CNC-Machine. To produce multiple replicas with sufficient quantities to fill the working section of a wind tunnel, copies of the master tile are made via moulding and casting techniques. A similar method was used by Nugroho et al (2013, 2014) for their surface roughness experiment.

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The end result of this planned project is a catalogue of data taken over a certain period of time to observe the build-up of the bio-fouling under normal operations and also to measure the changes in the skin-friction drag.

4. RESEARCH GROUP FORMATION AND ROLE

The large scale research project has a clear main objective, which is to understand the skin friction drag on ships hulls due to biofouling and to improve the efficiency of ship operations by providing a methodology and technology that can accurately quantify the emission and fuel usage penalty. In order for this endeavour to succeed, it requires the involvement of many different institutions, from academia, industry, to government representatives. Each of these institutions has their own specific role and expertise in order to meet the overarching aim. Here we will discuss the research group formation process and role for each of the stake-holders.

The research project is initially proposed by the University of Melbourne and Institute of Technology Sepuluh Nopember (ITS) through the newly formed Australian-Indonesian Centre (AIC) program in late 2014. The aim of the program is to establish and strengthen collaboration between Australian and Indonesian universities. As one of Indonesia's leading universities, ITS has a very strong marine technology faculty and strongly linked to various marine intuitions. The main role of ITS is to host the field experiment, use their extensive contacts in the maritime industry, assist with the import of various scientific apparatus from overseas, and liaise with local government representatives and recruit Masters students onto this project.

In order to allow the project to move forward ITS has invited PT Dharma Lautan Utama (DLU), an Indonesian passenger ship company, to be involved in the research project. The ship company has kindly provided the research team with access to a RO/RO passenger ferry called Dharma Kencana IX, as the test bed. The ferry is in operational status and serves between Merak and Bakaehuni, one of Indonesia's busiest lines. To ensure the safety of the proposed ship experiment for the entire duration of the investigation, ITS also invited Biro Klasifikasi Indonesia (BKI), Indonesian classification society, to be part of the research team. BKI is a recognized organization by Indonesian Government that is tasked by the Government to classify any Indonesian flagged marine transport both domestic and international that operates in Indonesian water and/or world wide voyage [DJPL, 2016]. They provide contribution in the form of technical evaluation regarding ship design, modification, reconstruction, maintenance and other dry-docking activities, in accordance with BKI technical standards (rules) for design and construction of ships and Indonesian Government maritime regulations.

As the initiator of the research project and part of the AIC research program, the University of Melbourne has several important roles. The first is to manage the overall research schedule. Secondly, the University's major contribution is in the form of field research equipment, such as the LDA, surface scanner, and other supporting research apparatus. Finally, they also host the laboratory investigation due to the institution's extensive experience in aerodynamic wind tunnel experiments. The University of Melbourne has a very strong fluid mechanics background and extensive laboratory facilities, furthermore it is relatively close to Indonesia. Therefore, it is an ideal location for the laboratory research.

Considering the scale of the experiment, the University of Melbourne invited Hempel A/S, a multinational antifouling company that is well versed in the research of biofouling to be part of the investigation. The company contributes in the form of antifouling technology that is applied on the hull of Dharma Kencana IX during dry docking when the hull is in clean state. Our main field of research activity is to measure the change of fluid flow on a ship's hull due to biofouling growth. However, the LDA method used on the ship is novel and unproven, hence it requires many repeated tests under constant conditions. Therefore, it is desirable that the ship hull's condition is unchanged during this time. The anti-fouling paint from Hempel A/S prevents biofouling from attaching and growing on the ship's hull for a longer period of time, permitting the field researchers to test the LDA during the key initial stages of this project. Furthermore, Hempel A/S also offers their technical expertise, industry contacts and extensive experience of the maritime industry.

Although at this stage the research team had secured the necessary facilities and equipment for the project to move forward, they still lacked the necessary personnel to perform the field and laboratory experiment. To overcome this challenge, ITS and the University of Melbourne invited The University of Southampton as part of the research team. The University of Southampton has a long history in naval and fluid mechanics research. The University of Melbourne and the University of Southampton have previously performed similar laboratory experiments, where they scanned a sample of tubeworm type fouling and characterised the drag using a wind tunnel (see Monty et al, 2016). Therefore the University of Southampton is well versed in this type of investigation.

In early 2015 ITS and the University of Southampton managed to secure funding from the UK government through the Newton fund program administered by the British Council, leveraging the previous funding from the AIC. The new funding allows the University of Southampton to recruit the necessary personnel to perform the field and laboratory experiment. Furthermore it allows the UK and Indonesian universities to fund the field travel expenses.

5. CORRELATION BETWEEN INDIVIDUAL FIELD OBJECTIVES

The challenge in this research collaboration is to satisfy each field's individual objective without sacrificing the overall goal. Here we will discuss each field's objective and how they connect with each other.

5.1 Academic Field Objective

In this research collaboration, the three academic institutions: ITS, the University of Melbourne, and the University of Southampton, have two targets, namely: to obtain further understanding about turbulent boundary layer flows over rough surfaces and to educate and train higher degree students.

First and foremost, although it is well known that biofouled hulls cause an increase of skin friction drag, leading to increases in power and fuel usage, our understanding of the turbulent flow over rough walls (such as a fouled hull) is still lacking. One of the main challenges in studying wall bounded turbulent flow, even over a smooth wall, is the seemingly quasi-random and complex motions inside the turbulent boundary layer. This challenge is exacerbated when the flow moves over uneven surfaces such as a fouled hull. The combined in-situ and laboratory experiments proposed will allow further understanding about the rough-walled turbulent boundary layer, particularly for realistic roughness. To the best of the author's knowledge this type investigation has never been performed before. The expected outcome from the project is a database with high research value. These results will be published in peer-reviewed journals and disseminated at conferences, allowing the three academic institutions to communicate their results to the scientific communities.

Apart from the research endeavour, this project provides opportunities for the academic institutions to train and educate graduate students, and also to provide crucial international / global experiences. The University of Melbourne uses this opportunity to design a capstone project that requires four Masters Students to perform an initial study for the image based surface scanner. The activity allows the students to master digital image reconstruction techniques and to apply their technical skill and engineering knowledge. The capstone Masters project also serves as an initial study for the Postdocs from the University of Southampton to continue and expand.

The research collaboration is particularly beneficial for ITS, as it allows them to train two Masters students. The two students come from a program called "Pre to Post MSc", funded by the Ministry of Research, Technology and Higher Education. The aim of this program is to train and educate high achiever graduate students at ITS from other smaller or younger Universities that are located in the eastern part of Indonesia. The students are later expected to return to their respective universities and work as university lecturers. The research project allows ITS to fund the student's travel expenses to the field research site and have them experience high level international research collaboration. This project also allows ITS to prepare more high achiever Masters students to be involved, particularly those aiming to continue their study in PhD at The University of Melbourne and The University of Southampton. These graduates are also expected to return to ITS as lecturers and contribute as part of the effort by ITS to be a world-class research university.

For ITS, the collaborative project also represents the three core roles for higher education in Indonesia, namely (1) education and teaching, (2) research and development of science, technology and arts, (3) community services. The three philosophies are more commonly known as TRI DHARMA PERGURUAN TINGGI, which should be developed simultaneously (Utama and Pribadi, 2011).

5.2 Industrial Field Objective

The collaborative research project involves two industrial representatives: PT DLU (passenger ship company) and Hempel A/S (manufacturer of antifouling coatings). The two firms are from different industries; however they are related and complement each other. As a passenger ship company, PT DLU earns revenues from transporting passengers (including trucks and cars) between islands in Indonesia. To boost profit, many ship companies require an effective and efficient ship operation management. Two of their largest sources of expenses are fuel and dry docking. Fouled hulls of ships results in higher fuel usage than a clean one, which translates to greater expenditure and emissions. In order to remove the biofouling from the hull and return it to the smooth state, the ship must undergo a dry docking process, which has a considerable financial cost. Furthermore, during dry docking the ship is unable to generate revenues, resulting in further losses. Note that the interval of dry docking varies for each type of ship on the basis of class society rules and administrator regulation. Passenger ships have to perform dry docking once a year (DJPL, 2014; BKI, 2016). During dry docking the ship's hull is cleaned, the underwater hull of the opening and closures in the shell related to the machinery system is checked and inspected. The ship hull is also protected with anti-fouling paint, a product that companies such as Hempel A/S produce.

For PT DLU, having a more informed decision in terms of operations will be beneficial. The proposed LDA device could eventually form part of the standard sensor suite on a modern ship, providing a constantly updating report on the health of the hull and the economic

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ramifications of the deteriorating hull smoothness. Furthermore, the surface scanner technique also has potential to be commercialised. In the future, ship operators and anti-fouling companies can use the surface scanner and database catalogue of various biofouling to predict a ship's excess fuel usage. The project also serves as a good opportunity for Hempel A/S to test their product and analyse the anti-fouling performance from a fluid dynamics perspective.

5.3 Policymaker Field Objective

As an institution that is tasked to classify any Indonesian flagged marine transport that operates in worldwide water and specially, Indonesian waters, BKI has an important role in advising the Indonesian Government regarding various marine safety, environmental protection, and procedures. One of the major outcomes of this research project is more detailed information regarding the energy and economic ramifications of a fouled ship hull. The information from the research can be used by BKI as a basis to review Government policy regarding the management of energy efficiency and biofouling treatment procedure. This would allow more economical and efficient ship operations. Furthermore, the policy can also be applied internationally through the International Maritime Organisation (IMO), where Indonesia is an active member. For developing countries such as Indonesia, research based policy is difficult to perform due to the country's low national research budget. Therefore this international research collaboration is a good opportunity to apply and integrate the research results into policy.

6. CONCLUSIONS

A large scale research collaboration between various institutions from four different countries that involves representatives from academia, industry and government policy makers is currently underway. The overall aim of the project is to understand the negative effect of growth of biofouling on a ship's hull in more detail and to come up with a method and technology that can quantify the energy usage penalty in order to improve the efficiency of ship operations.

Each of the six institutions involved have different roles and expertise that complement each other. The three academic institutions provide scientific expertise and apparatus. The two industry firms, a passenger ship company and manufacturer of anti-fouling solutions, have supplied the ship as a test bed and the anti-fouling technology respectively. Finally, the classification society provides technical advice, ensures the safety of the project, and provides avenues for the research to impact government policy. By collaborating together they leverage the value of the research viand are able to access funding from the Australian, Indonesian, and UK government.

Here we also have shown that despite the research team coming from various different fields, it is possible to form a joint project together. Each field (academia, industry, and policy maker), has different interests and individual objectives that are specific to their needs. The three academic institutions are interested to gain further understanding in rough wall turbulent boundary layers, to educate higher degree students, and to see their research impact a broader society. The two industrial firms are interested with the possible outcome of more efficient operations and new technology that can be applied. Finally, the Classification Bureau can provide a better policy based on the research outcomes. From the individual objectives of each field, one can immediately see that they are complementary and synergistic, making this a well-structured project By satisfying the requirements of each field, we are confident that the overarching aims of this project can be obtained.

7. ACKNOWLEDGEMENTS

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Jason Monty is an ARC Future Fellow and Associate Professor in Mechanical Engineering at The University of Melbourne. A/Prof Monty is an experimental researcher in Fluid Mechanics and is the leader of the Michell Hydrodynamics Laboratory at Melbourne, which houses several new and unique flow facilities and state-of-the-art instrumentation. A/Prof Monty has a broad range of research interests from arterial flows to wall-turbulence to wave mechanics. His major contributions to science have been in the field of turbulent boundary layers, which has led to new experimental programs in turbulent air-sea interactions and in-situ measurements of the boundary layer on a ship.

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