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Evaluation of Lift and Drag Force of Outward Dimple Cylinder Using Wind Tunnel

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ABSTRACT

Cylindrical structures are widely used especially in engineering field. The cylindrical structure produces large drag force due to pressure difference between upstream and downstream direction of the flow. The objective of this study is to fabricate cylindrical model that have 3 different surface characteristics which is smooth surface and outward dimple surface with covered half and full of cylinder surface. The second objective is to determine the drag and lift coefficient of a cylinder for all types of surface. Third objective is to visualize the flow separation of the cylinder for all surface. The experiment is tested in wind tunnel at various speed for lift and drag coefficient from 5.2 m/s to 30.5 m/s. For flow visualization test, the smoke test has been used at constant speed 3.5 m/s. The acting force on the cylinder that have been determined is coefficient of lift C_L and coefficient of drag C_D. The results are compared with the types of cylinder surface. The result gained showed that the smooth cylinder produce large drag coefficient compared to the dimple cylinder and this results are also agreed with the flow separation test which is the dimple cylinder are resulting in delayed flow separation point.

Keywords:
Flow around Cylinder, Dimple Cylinder, Reynolds Number, Smoke Visualization, Wind Tunnel Test

1. Introduction

Recently, numerous researches regarding renewable energy are being actively carried out in Malaysia due to the huge advantages towards the conservation of health and environment. Government of Malaysia also gives full support and encouragement to the academician and researchers to develop alternative renewable sources which are greener and environmental-friendly. The investigation of palm oil potential's as lubricant [1, 2], the study of nano-particle in various applications [3, 4, 5] and the development of wind tunnel [6, 7] are among the hot research areas that gain every researchers' attention today.

Cylindrical structures are widely used in engineering especially in offshore and marine engineering [8]. Due to wide applications of the flow around cylinder, recently many of researchers interested in this field. Drag reduction is the major objective for this research. Drag force is the force

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on an object that resists its motion through a fluid [9]. Drag coefficient, commonly denoted in fluid dynamics as C_D, C_x or C_w is a dimensionless quantity that describes a characteristic amount of aerodynamic drag caused by fluid flow, used in the drag equation [10]. Drag reduction of an object was influenced by the shape and surface of the object. Difference objects and difference surface will produce difference value of drag coefficient. Nowadays, a lot of research has been made regarding the method of reducing the drag force on cylinder, mostly by using passive vortex control methods either by changing the surface texture or by attaching protruding [11, 12, 13]. The theory of an ideal flow has described that the flow around cylinder can be replaced by the term of doublet. The doublet is formed when the combination of sink and source which is both was located at the same point. A cylinder can be built if there is two flow exist which is sink and source at the same location. The combination of stream function can be assumed as the cylinder.

The flow behavior around the cylinder are related to the Reynolds number where the Reynolds number is the ratio of inertial forces to viscous forces and is a convenient parameter for predicting if a flow condition will be laminar or turbulent and Re is defined as the Eq. (1).

$$R_e = \frac{\rho U D}{\mu} \quad (1)$$

Where Re, ρ, U, D and μ are Reynolds number, density of air, speed, cylinder diameter and kinematic viscosity respectively.

When the Reynolds numbers are small (1 and below), the flow behaves like a potential flow and there is no separation. The drag is all due to skin friction. As the Reynolds number is increased, this drag decrease and there is a separation of boundary layer, but the wake is of a limited length [14]. The circulating flow also called as eddies flow formed seem fixed behind the cylinder. For higher Reynolds numbers, the eddies flow breaks off from the cylinder. As the Reynolds number is increased, the eddies are continuously shed from the cylinder and washed downstream (Figure 1). Two rows of vortices are formed called the Vortex Street. Meanwhile, when the value for Reynolds number exceeds 3×10^6, the separation point slowly moves upstream as the Reynolds number is increased, resulting in an increase of the drag coefficient [15]. It should be noted that the critical Reynolds number at which the boundary layer undergoes transition is strongly affected by two factors which are the intensity of fluctuations existing in the approaching stream and the roughness of the surface.

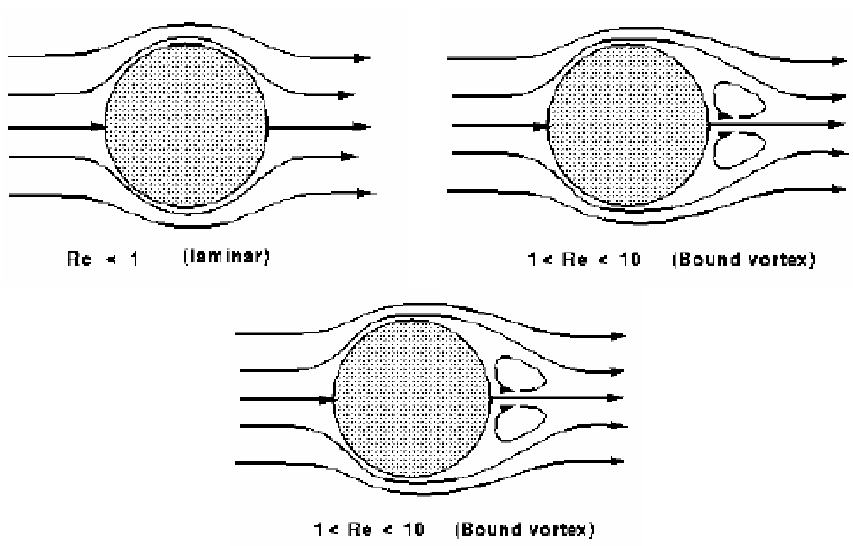

Fig. 1. Reynolds number on flow pass a cylinder [16]

A lot of researchers also work hard on the purpose of reducing the drag. Drag reduction is important in the engineering field. Basically, there are two categories of method in reducing the drag which is active and passive [17, 18]. One of the most effective drag reduction device are vortex generator. Vortex generators are passive flow-control devices that are commonly used on airfoils to prevent flow separation. The vortex generators were still widely used in practice for transport aircraft wing [19].

This paper will focus primarily on fabrication process of three types of cylinder surface which is smooth surface, outward dimple on half cylinder surface and outward dimple on full cylinder surface, evaluation of drag and lift coefficient of the test object for all types of cylinder surface by using wind tunnel and visualization analysis of the flow separation of the test object for all types of cylinder surface.

2. Methodology

In this project, circular cylinder with different surfaces have been used. Three PVC pipe with length of 289 mm and diameter of 60 mm have been used as the circular cylinder object. There are three types of surface for the test which is smooth surface, simple on half surface and dimple on full surface. Half round beads with diameter of 5 mm have been chosen as outward dimple material and this dimple are puts on the cylinder surface for half and full with the distance of two dimple is 11 mm. The fabricated model is shown in Figure 2. For the dimple on half surface, there are 4 types of orientation have been tested which is front, top, rear and bottom as shown in Table 1. The drag coefficient and smoke test have been done using the low speed wind tunnel.

Drag coefficient test was conducted at seven different speed which is 5.2, 7.4, 10.6, 15.4, 20.5, 25.5 and 30.5 m/s for each types and orientation of the cylinders. The drag coefficient from the experiment are used to calculate the drag force for each cylinders using the Eq. (2).

$$F_D = C_D \frac{1}{2} \rho A V^2 \quad (2)$$

Where F_D is the drag force in unit of Newton, A is the projected area of the cylinder exposed to the flow, ρ and V is the density and free stream velocity of the flow respectively. Projected area or A of the cylinder was calculated by multiplying length with the diameter of the cylinder. For smoke test, the constant speed which is 3.5 m/s or Reynolds number of 1.3×10^4 have been used to study the flow behavior and separation point of the cylinders. To generate flow pattern around cylinder, the 400W Fog Machine are used and the result are recorded using the DSLR camera.

Table 1
The orientation of the dimple on half cylinder

Orientation	Description
	Smooth Cylinder
	Outward dimple on full surface of cylinder
	Outward dimple on half surface of cylinder (FRONT)
	Outward dimple on half surface of cylinder (TOP)
	Outward dimple on half surface of cylinder (REAR)
	Outward dimple on half surface of cylinder (BOTTOM)

Fig. 2. Final product for test object which is smooth cylinder (a), outward dimple on half surface (b) and outward dimple on full surface (c)

3. Results

The experiment was conducted by using the low speed wind tunnel to perform the drag coefficient test and flow visualization test which is smoke test.

3.1. Drag Coefficient

The drag coefficient test was conducted on every types of cylinder which is smooth surface, dimple on full surface, dimple on half surface (FRONT), dimple on half surface (TOP), dimple on half surface (REAR) and dimple on half surface (BOTOM) cylinders. The results are shown in Table 2. The trend of the results can be see clearly in Figure 3 below, where smooth and dimple on half surface (REAR) are the highest drag coefficient while the other types of cylinder are lower drag coefficient. However, the trend of the drag coefficient for all types of the cylinders are decrease as the speed increased. This shows that the outward dimples are effective in reducing the drag coefficient of cylinders especially in low speed.

Table 2
Result of drag coefficient for all types of cylinders

No.	Velocity (m/s)	Drag Coefficient					
		Smooth Surface	Dimple Full Surface	Dimple Half Surface (FRONT)	Dimple Half Surface (TOP)	Dimple Half Surface (REAR)	Dimple Half Surface (BOTTOM)
1	5.2	0.6184	0.3784	0.4367	0.3558	0.6100	0.3184
2	7.4	0.5078	0.1178	0.3055	0.2055	0.5391	0.1078
3	10.6	0.4426	0.0526	0.0926	0.0526	0.4426	0.0651
4	15.4	0.4009	0.0349	0.0249	0.0249	0.3209	0.0495
5	20.5	0.3041	0.0271	0.0141	0.0398	0.2841	0.0398
6	25.5	0.2631	0.0201	0.0591	0.0348	0.2531	0.0257
7	30.5	0.2247	0.0283	0.0763	0.0243	0.2647	0.0180

The result of the full surface dimpled cylinder are compared with four position of half surface dimpled cylinder which is front, top, back and bottom at seven different speed between 5.2 m/s to 30.5 m/s and presented in the Figure 3. The x-axis represent the speed in m/s while y-axis shows the results of drag coefficient (C_D) for each speed taken. Based on the Figure 3, we can see that the drag coefficient of the rear half surface dimpled cylinder is higher than the other cylinders at speed of 5.2 m/s to 30.5 m/s. The trend for all the cylinders are decrease when the speed is increase. However, for the full surface dimpled cylinder, front, top and bottom half dimpled cylinders, the trend is slightly different with the rear half surface dimpled cylinder which is drastically decrease at the speed 5.2 m/s until speed reached 10 m/s. This trend changed when the speed above 10 m/s which is gradually decrease to the speed of 30.5 m/s. This shows that the statement of the rear half surface dimpled cylinder is not effective in reducing the drag coefficient is acceptable [20, 21].

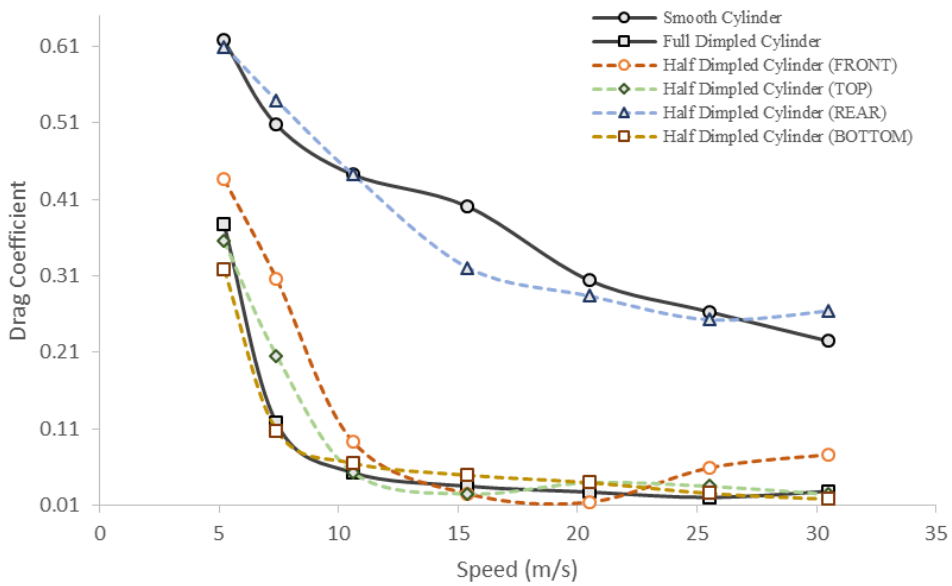

Fig. 3. Graph of Drag Coefficient against speed for all types of cylinders

3.2. Lift Coefficient, C_L

The results of lift coefficient for all types of cylinders which is smooth, full surface dimpled, top half surface dimpled, front half surface dimpled, rear half surface dimpled and bottom half surface dimpled cylinders at seven different speed are compared in Figure 4. The x-axis represent the speed in m/s while y-axis shows the results of lift coefficient (C_L) for each speed taken. Based on Figure 4, it can be seen clearly that the lift coefficient (C_L) values are affected considerably by the dimple pattern as well as the orientation of the half surface dimple with respect to the incident flow but in very small values that closed to the 0 value.

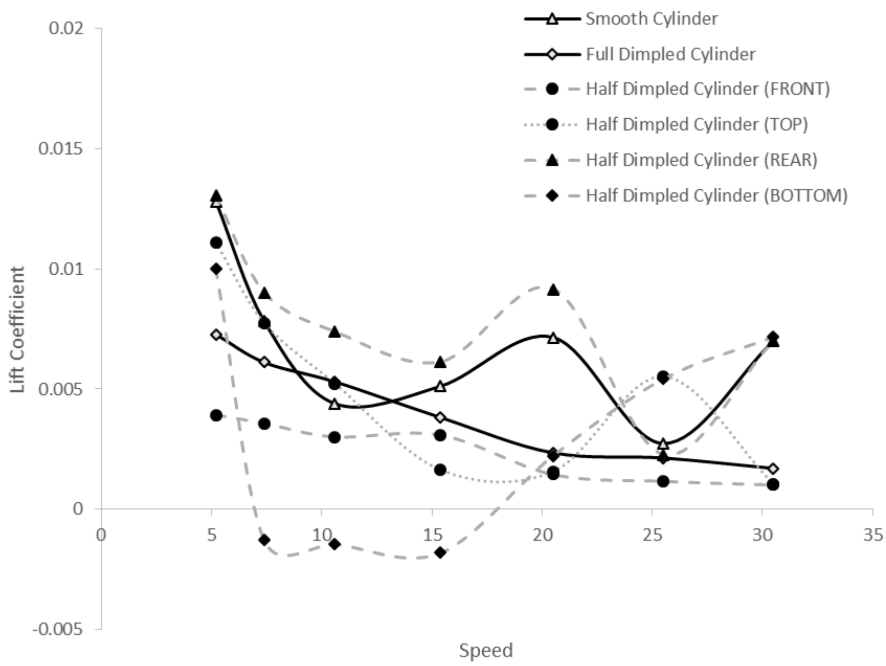

Fig. 4. Graph of Lift Coefficient against Speed for all types of cylinders

The trend for all types of the cylinders are fluctuates as speed is increase. For the bottom half dimpled cylinder, the trend is drastically decrease from the positive value to the negative value of lift coefficient (C_L) at speed 5.2 m/s to 7.4 m/s. The trends for this types of cylinders continues fluctuates at negative values until the speed of 15.4 m/s. After that, it gradually increase to the positive value of lift coefficient (C_L) until the speed reached 30.5 m/s. The negative values show that, the effect of the dimple surface on the bottom surface of cylinder can reduce the pressure on that area causes downward lift coefficient of downforce results in negative value. In term of reduction in lift coefficient (C_L), the front half dimpled cylinders appears more effective within the speed range of this experiments.

3.3. Flow Visualization

To relate the results of the drag coefficient, the flow visualization test has been conducted. This is because the delay of separation point will result in lower drag coefficient for the cylinders [22]. The Figure 5 shows the flow separation point with the aid of the red arrow as the flow separation point start. It can be seen clearly that the effects of the outward as the vortex generator are effectively in delaying the separation point. For example, as shown in Figure 5(a) and Figure 5(b) which are smooth cylinder and dimple on full surface of cylinder respectively, the flow separation of the smooth cylinder is at the angle below 90 degrees while for the dimple on full surface of cylinder, the flow separation is delayed at the angle higher than 90 degrees. It shows that drag coefficient also lower and these results are agreed well with the drag coefficient test results [23].

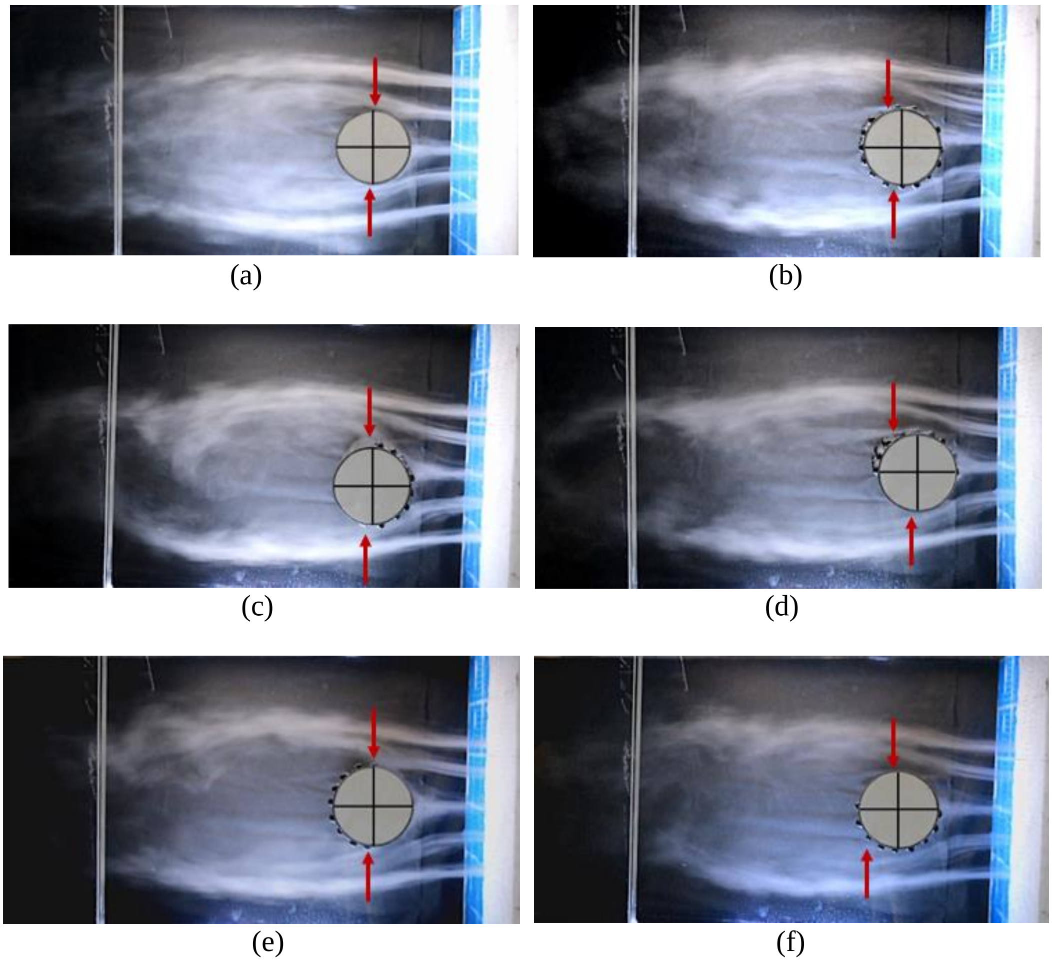

Fig. 5. Flow visualization test results for all types of cylinder

With the presence of the dimple, vortex is generated, smaller recirculating zone formed and the pressure drag are reduced. This smoke visualization results agrees well with the [24] stated that the smaller the recirculation zone results in the lower drag coefficient. The smoke visualization test results also parallel to the drag coefficient (C_D) test which is the smallest drag coefficient (C_D) are produced by the full dimpled cylinder. It can be concluded that the dimple surface is efficient to produces smaller wake compare to smooth cylinder. Dimple cylinder also effective in delaying the separation point that can results in smaller drag coefficient (C_D).

4. Conclusions

In this research, the effect of the outward dimple surface which is outward dimple on the surfaces of the cylinders towards the drag coefficient has been analysed. The low speed wind turbine has been used to run this experiment. From the results that have been gained from the drag coefficient test, we can conclude that, outward dimple on the cylinder surface are effectively in reducing the drag coefficient compared to the smooth cylinder surface. As we can see, at speed of 7.4 m/s, the drag coefficient for smooth cylinder is 0.5078, however, the drag coefficient of the dimple on full surface of cylinder, the drag coefficient at the same speed is 0.1178 which is much lower.

To study about the flow separation, smoke test has been used in this experiment at constant speed of 3.5 m/s. From the observation of the flow behaviour over the cylinder, the outward dimple is effectively in reducing in drag coefficient for cylinder especially in low speed. This is because, the outward dimple effects as the vortex generator that delay the separation point as shown with red arrow in Figure 3 above. For example, from Figure 3(a) and Figure 3(b) which is smooth and full dimple surface respectively, the flow separation point for the smooth cylinder are before the 90 degree of angle. However, for the full dimple cylinder, the flow separation point at the angle above 90 degrees which is delayed the flow separation and resulting in low drag coefficient.

As the conclusion, the results of the drag coefficient test and flow visualization test are parallel. The outward dimple can be the best passive device as the vortex generator that can be used to delay the flow separation point that resulting in low drag force produced by the cylinder. The objective of this study is archived.

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References
[1] Noorawzi, Nuraliza, and Syahrullail Samion. "Tribological effects of vegetable oil as alternative lubricant: a pin-on-disk tribometer and wear study." *Tribology Transactions* 59, no. 5 (2016): 831-837.
[2] Razak, D. M., S. Syahrullail, N. Sapawe, Y. Azli, and N. Nuraliza. "A new approach using palm olein, palm kernel oil, and palm fatty acid distillate as alternative biolubricants: improving tribology in metal-on-metal contact." *Tribology Transactions* 58, no. 3 (2015): 511-517.
[3] Sidik, Nor Azwadi Che, Muhammad Noor Afiq Witri Muhammad Yazid, Syahrullail Samion, Mohamad Nor Musa, and Rizalman Mamat. "Latest development on computational approaches for nanofluid flow modeling: Navier–Stokes based multiphase models." *International Communications in Heat and Mass Transfer* 74 (2016): 114-124.
[4] Sidik, Nor Azwadi Che, Muhammad Noor Afiq Witri Muhammad Yazid, and Syahrullail Samion. "A review on the use of carbon nanotubes nanofluid for energy harvesting system." *International Journal of Heat and Mass Transfer* 111 (2017): 782-794.
[5] Ghaderian, Javad, Nor Azwadi Che Sidik, Alibakhsh Kasaeian, Sepideh Ghaderian, Amir Okhovat, Amirabbas Pakzadeh, Syahrullail Samion, and Wira Jazair Yahya. "Performance of copper oxide/distilled water nanofluid in

evacuated tube solar collector (ETSC) water heater with internal coil under thermosyphon system circulations." *Applied Thermal Engineering* 121 (2017): 520-536.
[6] Muhammad Faiz Rozaim, Fazila Mohd Zawawi, Nur Safwati Mohd Nor, Haslinda Mohamed Kamar, Nazri Kamsah. "Experimental study on performance of low speed wind turbine for application in Malaysia." *Journal Of Advanced Research In Fluid Mechanics And Thermal Sciences* 26*,* no. 1 (2016): 20-28.
[7] Majunit, Nurul Izyan, Fazila M. Zawawi, Nur Safwati Mohd Nor, Haslinda Mohamed Kamar, and Nazri Kamsah.. "Numerical investigation of vortex formation effect on horizontal axis wind turbine performance in low wind speed condition." *Journal Of Advanced Research In Fluid Mechanics And Thermal Sciences* 27*,* no. 1 (2016): 1-11.
[8] Mohamad Nor Musa, Syahrullail Samion, Mohd Kameil Abdul Hamid, Wan Mohamad Aiman Wan Yahya, Eriza Paiman. "Study on Water Hammer Effect in Turbulent Flow through the Pipe System." *Journal Of Advanced Research In Fluid Mechanics And Thermal Sciences* 50, no. 2 (2018): 122-133.
[9] Zhou T., Razali S. M., Hao Z., & Cheng L. "On the study of vortex-induced vibration of a cylinder with helical strakes." *Journal of Fluids and Structures 27*, no. 7 (2011): 903-917.
[10] Sovran, Gino. *The Effect of Ambient Wind on a Road Vehicle's Aerodynamic Work Requirement and Fuel Consumption.* No. 840298. SAE Technical Paper, 1984.
[11] Güven, Oktay, C. Farell, and V. C. Patel. "Surface-roughness effects on the mean flow past circular cylinders." *Journal of Fluid Mechanics* 98, no. 4 (1980): 673-701.
[12] Lo, K. W., and N. W. M. Ko. "Vortex interaction in the formation region of a grooved circular cylinder" *Fluid dynamics research* 24, no. 3 (1999): 161.
[13] Huang, Shan. "VIV suppression of a two-degree-of-freedom circular cylinder and drag reduction of a fixed circular cylinder by the use of helical grooves" *Journal of Fluids and Structures* 27, no. 7 (2011): 1124-1133.
[14] Maxworthy, Tony. "Experiments on the flow around a sphere at high Reynolds numbers" *Journal of Applied Mechanics* 36, no. 3 (1969): 598-607.
[15] Quintavalla, Steven J., Alexander J. Angilella, and Alexander J. Smits. "Drag reduction on grooved cylinders in the critical Reynolds number regime." *Experimental Thermal and Fluid Science* 48 (2013): 15-18.
[16] School of Engineering and Electronics, The University of Edinburgh
[17] Altaf, Alaman, Ashraf A. Omar, and Waqar Asrar. "Review of passive drag reduction techniques for bluff road vehicles*." IIUM Engineering Journal* 15, no. 1 (2014).
[18] Sidik, Nor Azwadi Che, Syahrullail Samion, Javad Ghaderian, and Muhammad Noor Afiq Witri Muhammad Yazid. "Recent progress on the application of nanofluids in minimum quantity lubrication machining: A review." *International Journal of Heat and Mass Transfer* 108 (2017): 79-89.
[19] Khoshvaght-Aliabadi, M., O. Sartipzadeh, and A. Alizadeh. "An experimental study on vortex-generator insert with different arrangements of delta-winglets." *Energy* 82 (2015): 629-639.
[20] Korkischko, I., and J. R. Meneghini. "Experimental investigation of flow-induced vibration on isolated and tandem circular cylinders fitted with strakes." *Journal of Fluids and Structures* 26, no. 4 (2010): 611-625.
[21] Kimura, Takeyoshi, and Michihisa Tsutahara. "Fluid dynamic effects of grooves on circular cylinder surface." *AIAA journal* 29, no. 12 (1991): 2062-2068.
[22] Zhou, Bo, Xikun Wang, Wie Min Gho, and Soon Keat Tan. "Force and flow characteristics of a circular cylinder with uniform surface roughness at subcritical Reynolds numbers." *Applied Ocean Research* 49 (2015): 20-26.
[23] Williamson, C. H. K., and R. Govardhan. "Vortex-induced vibrations." *Annu. Rev. Fluid Mech*. 36 (2004): 413-455.
[24] Zhou, Bo, Xikun Wang, Wei Guo, Wie Min Gho, and Soon Keat Tan. "Experimental study on flow past a circular cylinder with rough surface." *Ocean Engineering* 109 (2015): 7-13.