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AERODYNAMIC ANALYSIS OF SPEEDO FASTSKIN-I SWIMSUIT

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***Abstract**- Swimming is one of the most energy intensive sporting events, where a winner is decided by a short margin. The winning time margin can be increased by various means, including engineered outfits within the game's regulations. In swimming, apart from optimisation of the swimmer's body, an appropriately devised swimsuit can play a significant role in reducing the drag, thereby enhancing the winning time margin. The main motivation for undertaking this study stems from the increasing levels of technical sophistication in the swimsuits that are claimed by the manufacturers for performance enhancement. Therefore, the goal of this paper is to undertake an experimental study with microscopic illustration of the swimsuit fabric, and its effects on aerodynamic properties. The study utilised a commercial swimsuit under stretched and un-stretched conditions of fabric morphology, and their impact on aerodynamic drag. This study was conducted using a wind tunnel for a range of Reynolds numbers. The simplified body shape was used to determine the aerodynamic drag. The finding of this study illustrates that there is a significant difference between the aerodynamic drag for the stretched and un-stretched surface morphology of the Speedo FS-I swimsuit. Furthermore, the microscopic analysis of the stretched and un-stretched fabric was undertaken to extend our understanding.*

Keywords: Swimsuit, aerodynamic drag, wind tunnel, Speedo, electron microscope.

1. INTRODUCTION

Improvement of aerodynamic performance is critical in a high-speed sport such as swimming. Swimming became one of the major athletic sports and top 10 new sports technologies. The competitive swimming event consists of different distances from 50 m to 1500 m. These events required excessive energy and speed to achieve best recorded within short wining time margins. Prior studies estimate over 90% of the swimmer's power output is spent overcoming hydrodynamic resistances [1, 2]. These resistive forces were essentially behind the generation of drag during swimming. Reducing the hydrodynamic resistance can significantly improve overall swimming performance [3]. The hydrodynamic resistance can generally be divided into two categories: (i) passive resistance and (ii) active resistance. The passive resistance is generally measured by towing the swimmer without any physical movements [1, 4, 5]. The passive drag is directly influenced by the body shape and outfits. The active resistance is measured for the swimmer during swimming with the physical movement. The active drag can be found once the propulsive force is computed.

Vorontsov et al. [1] and Toussaint et al. [8, 9] have suggested that the overall drag affecting a swimmer and could be categorized as: (i) form drag, (ii) wave drag, and (iii) skin friction drag. Form drag is the resistance to motion due to the shape of the body, the wave drag is associated with the work required to generate waves and skin friction is the resistance to motion due to the surface area of the body. The form and skin friction drag depend on the Reynolds number (Re) while the wave drag depends on the Froude number (Fr):

$$\mathrm{Re} = \frac{\rho V l}{\mu} \quad (1)$$

$$Fr = \frac{V}{\sqrt{gl}} \quad (2)$$

In competitive swimming, hundredths of a second can separate gold from bronze. At present, most competitive swimmers attempt to take advantage of various means including swimsuits to enhance their performance. The modern swimsuits have evolved through a series of style changes and designs over the decades to its current nice aesthetic look and with possible drag reduction advantages [10, 15]. More recently, several commercial swimsuit manufacturers have claimed and counterclaimed about their swimsuits performance by reducing hydrodynamic resistance and enhancing buoyancy. Since the Beijing Olympic Games 2008, almost all major manufacturers introduced full-body swimsuits made of semi and full polyurethane combined with woven Lycra and Nylon. Most publicised swimsuits of these categories are Speedo, TYR, Arena and Diana. Notably, out of 32 swimming events (16 for male and 16 for female), 21 world records have been broken in last Beijing Olympic Games. The manufacturers claimed these suits have features such as ultra-light weight, water repellence, muscles oscillation and skin vibration reduction by compressing the body.

Strangwood et al. [11], Chowdhury et al. [12, 13] and Moria et al. [10, 15] revealed that technological innovation in both design and materials has played a crucial role in sport achieving its current standing in both absolute performance and its aesthetics. Currently, swimsuits have been aggressively marketed primarily as a means for reducing the skin friction component of the total drag, thereby conferring a competitive advantage over other swimmers. However, it is difficult to find independent research in the open literature that supports these claims and counter claims [2]. In order to understand the aerodynamic contribution of swimsuits, the current study was undertaken in the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University.

2. EXPERIMENTAL PROCEDURE

2.1 Macro Scale Testing

The human body is not a streamlined shape and caused a lot of flow separations around it. The drag generated by the body (pressure, wave & friction drag) is significantly larger than the drag generated by swimmers outfits (textile). The drag generated by the swimsuit must be evaluated in isolation and in macro scale testing, see Figure 1. A standard cylinder methodology was used to measure the drag generated by swimsuit materials. Based on the macro scale test, an engineered swimsuit can be developed to gain aerodynamic advantages.

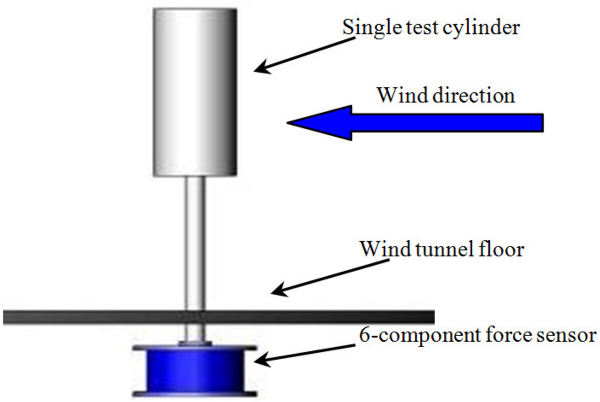


Fig.1: Schematic of cylinder methodology [10]

2.2 Experimental Procedure

With a view to obtain aerodynamic properties experimentally for a commercially available swimsuit (Speedo FS-I) made of two materials composition, 110 mm and 90 mm diameter cylinders were manufactured. In order to test the fabric without applying any tension (un-stretched), the 90 mm diameter cylinder would be used. On the other hand, the 110 mm diameter cylinder would be used to test the fabric with some measured tension (stretched condition). Both cylinders were made of PVC material and used some filler to make it structurally rigid. Both cylinders were vertically supported on a six component sensor (type JR-3) that had a sensitivity of 0.05% over a range of 0 to 200 N. The aerodynamic forces and their moments were measured for a range of Re numbers based on cylinder diameter and varied wind tunnel air speeds (from 10 km/h to 130 km/h with an increment of 10 km/h). Each test was conducted as a function of swimsuit's seam positions and varied fabric tension (see Figure 2).

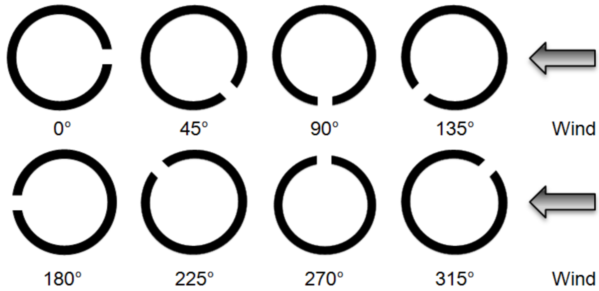


Fig. 2: Seam orientation at different angles facing the wind during the test (Plan view)

2.3 Experimental Facilities

The RMIT Industrial Wind Tunnel was used to measure the aerodynamic properties of swimsuit fabrics. The tunnel is a closed return circuit wind tunnel with a turntable to simulate the cross wind effects. The maximum speed of the tunnel is approximately 150 km/h. The rectangular test section dimensions are 3 meters wide, 2 meters high and 9 meters long, and the tunnel's cross sectional area is 6 square meters. A plan view of the tunnel is shown in Figure 3. The tunnel was calibrated before and after conducting the experiments and air speeds inside the wind tunnel were measured with a modified National Physical Laboratory (NPL) ellipsoidal head Pitot-Static tube (located at the entry of the test section) which was connected through flexible tubing to a Baratron pressure sensor made by MKS Instruments, USA. The cylinder was connected through a mounting sting with the JR-3 multi-axis load cell, also commonly known as a 6 degree-of-freedom force-torque sensor made by JR-3, Inc., Woodland, USA. The sensor was used to measure all three forces (drag, lift and side forces) and three moments (yaw, pitch and roll moments) at a time. Each set of data was recorded for 20 seconds time average with a frequency of 20 Hz ensuring electrical interference is minimised. Multiple data sets were collected at each speed tested and the results were averaged for minimising the further possible errors in the experimental raw data. Further details about the wind tunnel can be found in Alam et al. [16].

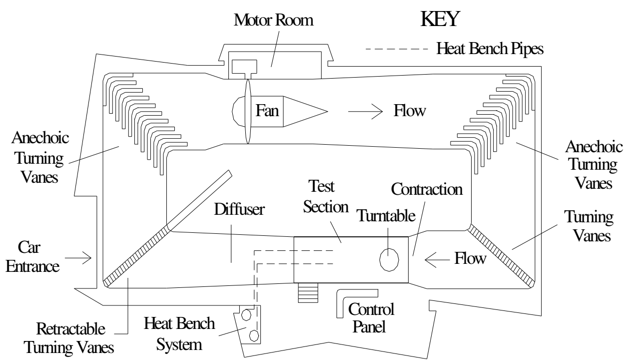


Fig. 3: A plan view of RMIT Industrial Wind Tunnel [16]

Both bare cylinders were tested initially in order to benchmark the aerodynamic performance as shown in Figure 4 (a & b). Then the two cylinders were wrapped with swimsuit fabric to measure their aerodynamic forces and moments. The end effects of the bare cylinder were also considered [12].

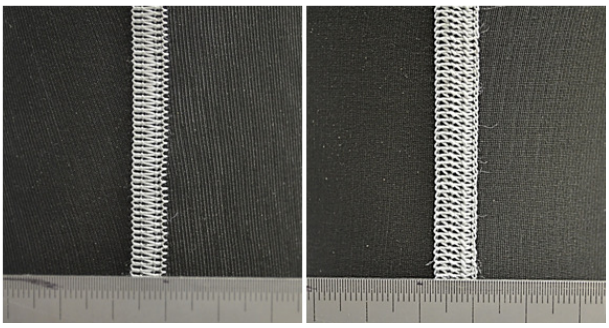
(a) 110 mm diameter and 220 mm length for stretched fabric

(b) 90 mm diameter and 220 mm length for un-stretched fabric

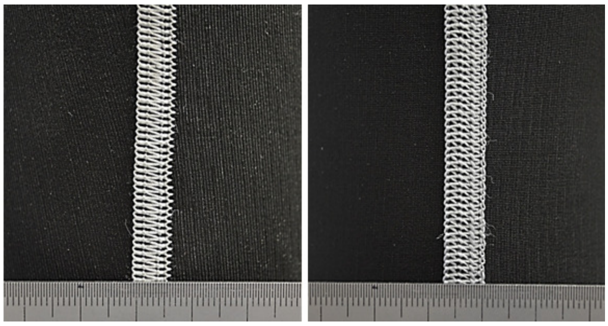
Fig.4: Experimental bare cylinders set up in RMIT Industrial Wind Tunnel

2.4 Swimsuit Materials

A brand new Speedo Fastskin-I (FS-I) swimsuit material has been selected for this study as it was officially used in the 2000 Sydney Olympic Games. It is made of 74% polyester and 26% Elastane (Lycra). The seam was made using four-way flat lock method which has 22 stitches per inch. Figure 5 (a & b) shows the inner and outer seam for stretched and un-stretched fabric material. Also, Figure 6 (a to d) shows the four seam positions (stretched and un-stretched fabric) used in this study.

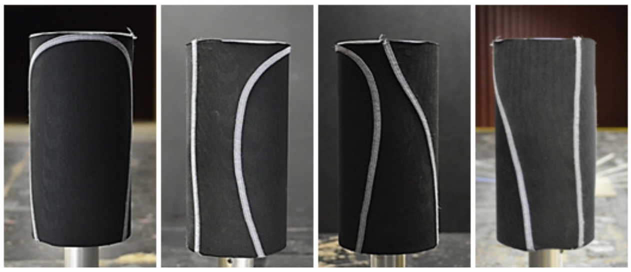


(a) Outer seam joint (left) and inner seam joint (right) for the stretched fabric



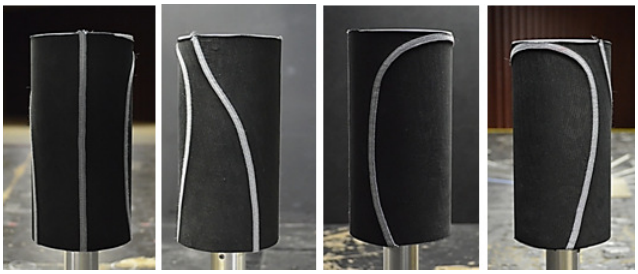
(b) Outer seam joint (left) and inner seam joint (right) for the un-stretched fabric

Fig. 5: Combined optical images of the Speedo FS-I seam joint for stretched and un-stretched fabric material



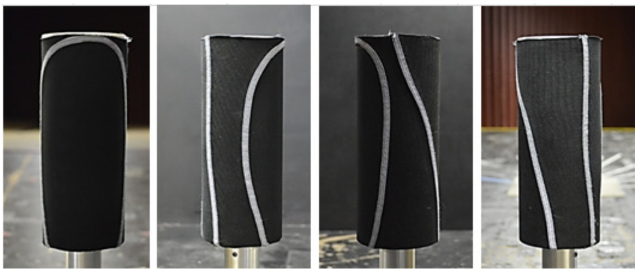
Front View Left View Right View Back View

(a) Position 1 for stretched fabric



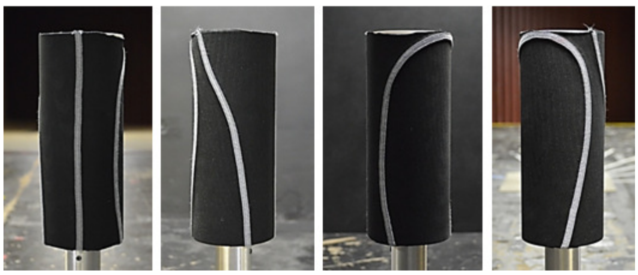
Front View Left View Right View Back View

(b) Position 2 for stretched fabric



Front View Left View Right View Back View

(c) Position 3 for un-stretched fabric



Front View Left View Right View Back View

(d) Position 4 for un-stretched fabric

Fig.6: All four seam positions

3. RESULTS AND DISCUSSION

3.1 Microstructure Analysis

As mentioned earlier, the purpose of using two different sizes of the cylinder is to measure the effect of aerodynamic properties in stretched and un-stretched fabric material. Figure 7 (a & b) shows optical images for the un-stretched material of Speedo FS-I (inner and outer surface) while Figure 8 (a & b) shows the stretched fabric material. The optical images did not show a notable difference in the surface profile. Therefore, an Electron microscope was used to illustrate the swimsuit material features at 3000 times magnification as shown in Figure 9.

(a) Outer surface material

(a) Inner surface material

Fig. 7: Optical images of un-stretched Speedo FS-I fabric material

(a) Outer surface material

(a) Inner surface material

Fig. 8: Optical images of stretched Speedo FS-I fabric material

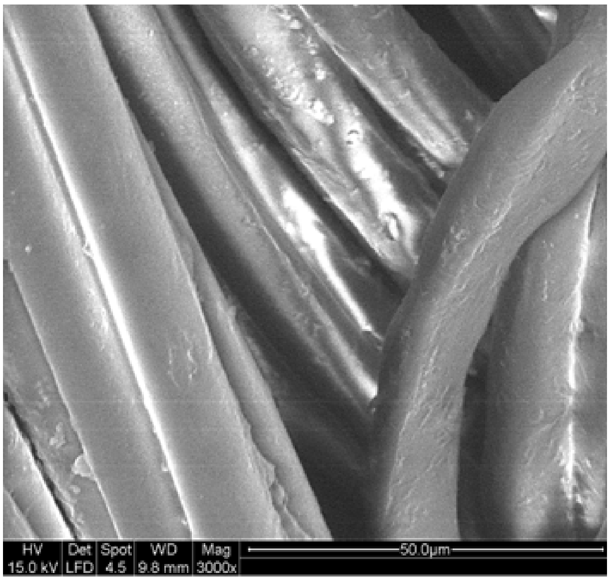


Fig. 9: Surface profile of Speedo FS-I swimsuit material using an Electron Microscope (3000X magnification)

3.2 Aerodynamic Analysis

In this paper, only drag force (D) data, and its dimensionless quantity drag coefficient (C_D), are presented. The C_D was calculated by using the following formula:

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 A} \quad (3)$$

The drag force (D) versus wind speed (V) and the drag coefficient (C_D) as a function of Re for a range of seam positions for the tested Speedo FS-I swimsuit material are presented in Figures 10 to 15. In order to compare the results of swimsuit (stretched and un-stretched material), the drag force (D) and C_D for both bare cylinders were also shown in all figures. Figure 10 shows that the drag for the bare cylinder (smooth) which is continuously increasing without any abrupt changes as expected. The C_D variation with Re as shown in Figure 11 clearly indicates that swimsuit fabric material has undergone a gradual drag crisis (transition effect from laminar to turbulent flow regimes at a speed range of 20 to 50 km/h) for the position 2. The position 1 enhances the favourable pressure gradient more and delays the separation by increasing the turbulent boundary layer compared to other seam positions. In general, the rougher surface of the swimsuits extends the turbulent boundary layer by reducing the length of laminar boundary layer and ultimately delays the flow separation in comparison with the smooth surface of bare cylinder. Furthermore, position 2 is not favourable for the drag reduction as it triggers an early flow separation compared to the seams position 1.

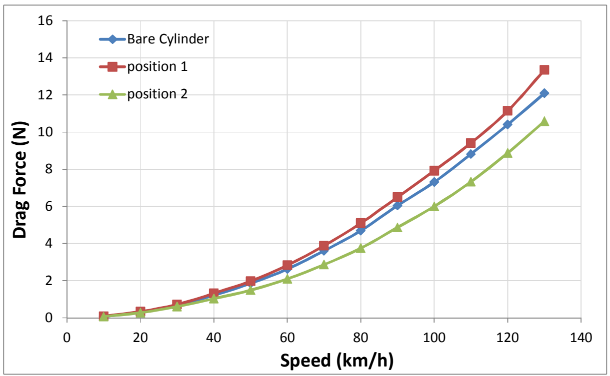


Fig. 10: Drag variation with speeds (stretched fabric material)

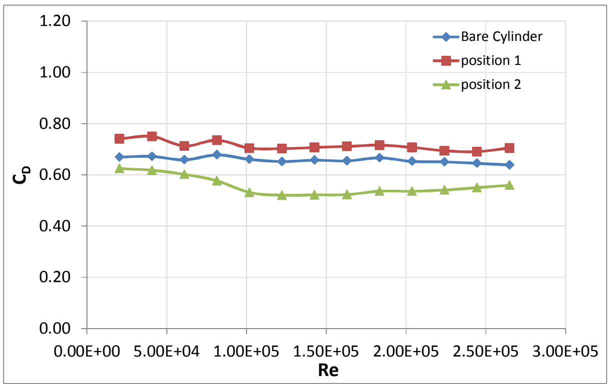


Fig. 11: C_D variation with Re (stretched fabric material)

The drag and the C_D values for the un-stretched Speedo FS-I swimsuit material are shown in Figures 12 and 13. The seams at position 3 have the higher drag and C_D values compared to the bare cylinder while the other tested case showed a similar trend of the bare cylinder. Also, there is no clearly noted transitional effect on the drag and C_D for the both cases (position 3 & 4).

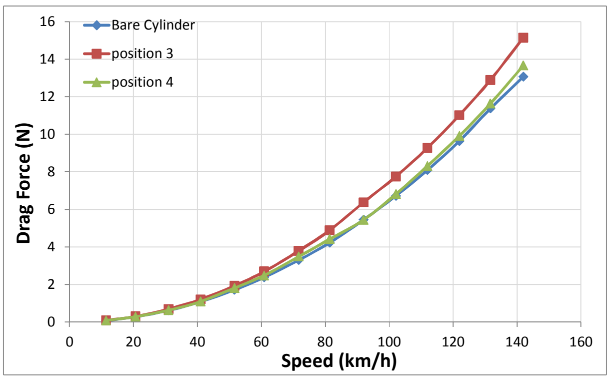


Fig. 12: Drag variation with speeds (un-stretched fabric material)

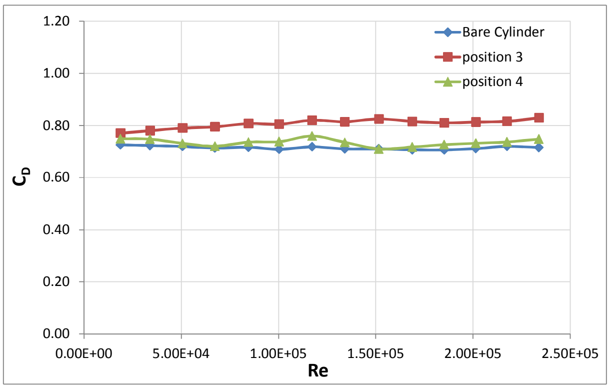


Fig. 13: C_D variation with Re (un-stretched fabric)

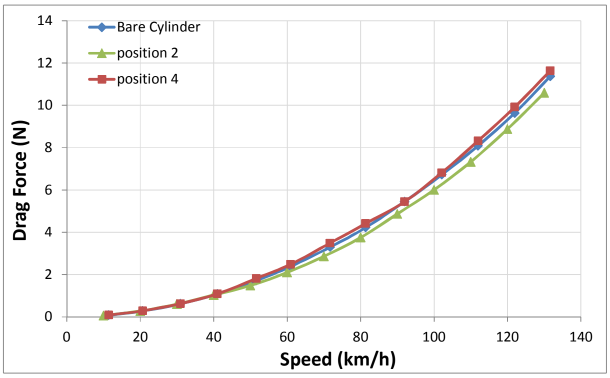


Fig.14: Comparison of Drag variation with Speeds (stretched and un-stretched fabric material)

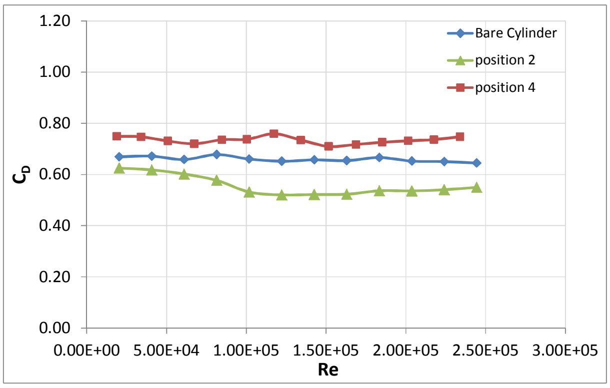


Fig.15 Comparison of C_D variation with Re (stretched and un-stretched fabric material)

A comparison of drag and C_D values for the stretched and un-stretched Speedo FS-I swimsuit material is shown in Figures 14 and 15 respectively. It is evident that the stretched material has the lowest value of drag coefficient after transition to the un-stretched material. Although un-stretched material has no transitional effect, it has relatively higher C_D values. This condition of un-stretched material does not provide any aerodynamic advantages. Both fabric materials (stretched and un-stretched) have complicated effects on aerodynamic properties. It is not clear what contribution was made by the fabric surface (stretched and un-stretched) or the complexity made by the seam orientations. However, it is expected that all these variables (stretched and un-stretched surface morphology and seam orientation) have flow transitional effect compared to the bare cylinder surface. The effects of surface morphology alone on the transitional effect can be found in by Moria et al. [16].

4. CONCLUSIONS

The following concluding remarks have been drawn based on the experimental study presented here:

- The surface structure (roughness and seam) of the swimsuit has significant effect on the aerodynamic drag.
- The stretched Speedo FS-I fabric material has relative advantages due to lower C_D values at speeds below 50km/h wind speed or equivalent speeds in water.
- The C_D value of un-stretched Speedo FS-I fabric material is independent of Reynolds number as it did not undergo any flow transition.
- The flow transition can be manipulated in order to gain aerodynamic/hydrodynamic advantages by using engineered fabric material and seam positions.
- Although not identified individually, the combined effect of surface roughness and seam orientation on aerodynamic behavior is well noted.

5. ACKNOWLEDGEMENT

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7. NOMENCLATURE

Symbol	Meaning	Unit
C_D	Drag Coefficient	
D	Drag Force	(N)
ρ	Fluid (air/water) Density	(kg/m^3)
V	Wind Speed	(m/s)
A	Projected Frontal Area of Cylinder	(m^2)
d	Diameter of Cylinder	(m)
μ	Dynamic Viscosity	(N.s/m^2)