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AERODYNAMICS AND MICROSTRUCTURE STUDY OF DIANA SUBMARINE SWIMSUIT

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ABSTRACT

Science and technology can play an important role in achieving better outcomes in sports. In speed sports, aerodynamics is considered to be one of the decisive factors in winning margins. By streamlining the exposed body configuration in the fluid, the aerodynamic resistance can considerably be reduced. In swimming, it is claimed that utilising the full body swimsuit, the performance can be enhanced. However, there is not enough scientific data available in the open literature to support this claim. Moreover, it is not clear how a swimsuit can minimize aero/hydrodynamic drag. Therefore, the main objective of this work is to study the microscopic effect of swimsuit materials on aero/hydrodynamic behaviour under stretched and un-stretched conditions of the swimsuit material. The study was conducted experimentally for a range of Reynolds numbers. A specially developed cylindrical methodology was used to quantify the effects of swimsuit materials on aerodynamic properties. A microscopic analysis of swimsuit materials was also undertaken. The findings indicated that the aerodynamic properties are dependent on the swimsuit surface structure.

Keywords: Swimsuit, Aero/hydrodynamic Drag, Wind Tunnel, Speedo, Electron Microscope.

1. INTRODUCTION

Improvement of aerodynamic performance is critical in high-speed sports such as swimming. Swimming became one of the major technology intensive sports since 2008 Beijing Olympic Games. The competitive swimming event consists of different distances from 50m to 1500m. These events required huge energy and speed to achieve best record within short wining time margins. Studies estimate that 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 in 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. [6, 7] have suggested that the overall drag of a swimmer can be categorized as form drag, wave drag, and 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 wetted surface. The form and skin friction drag depend on the Reynolds number (Re):

$$\mathrm{Re} = \frac{\rho V l}{\mu} \tag{1}$$

The wave drag depends on the Froude number (Fr):

$$Fr = \frac{V}{\sqrt{gl}} \tag{2}$$

In competitive swimming, where hundredths of a second can separate the winner from the loser, the hydrodynamic drag minimization can play a positive role. 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 form [8, 9]. The aero/hydrodynamic behavior of modern swimsuits is not well studied and reported to the public domain. What sort of advantages especially the aero/hydrodynamic aspects are gained by using these well publicized swimsuits are not known. It is believed that the surface morphology of commercial swimsuit could play a vital role in aero/hydrodynamic advantages [10]. Therefore, the primary objectives of this study are to experimentally study of aerodynamic behavior of a commercial swimsuit "Diana" under a range of wind speeds and surface morphology under tension and without tension. Moreover, it is well known that the technological innovation in both design and materials has allowed achieving its current standing in both absolute performance and its aesthetics (e.g., Strangwood et al. [11], Chowdhury et al. [12, 13] and Moria et al. [10, 14]).

2. EXPERIMENTAL PROCEDURE AND METHOD

2.1 Description of 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). Therefore, the drag generated by the swimsuit must be evaluated in isolation by using a macro scale testing. In order to measure the aerodynamic properties of the swimsuit material, a macro scale testing methodology using a standard cylinder has been developed in RMIT University. The schematic view of this standardized macro scale testing methodology using a cylinder is shown in Figure 1.

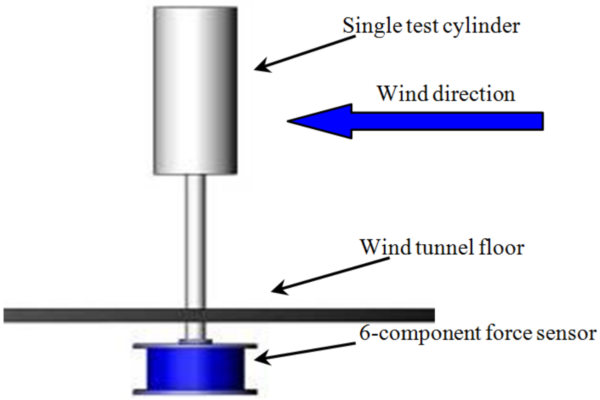
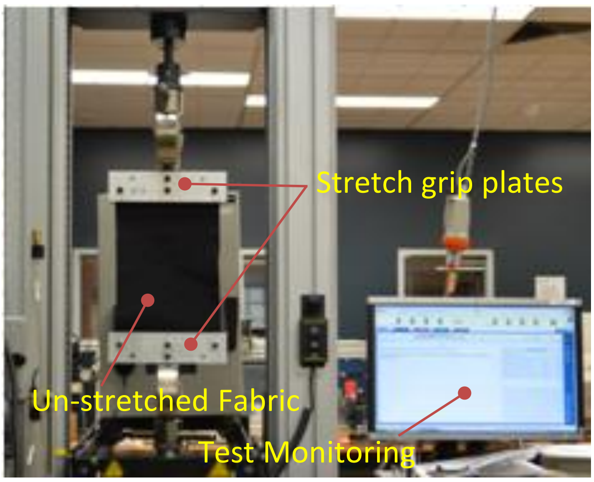


Fig 1. Schematic CAD model of bare cylinder in RMIT Industrial Wind Tunnel [8]

With a view to obtain aero/hydrodynamic properties experimentally for a commercially available swimsuit, a 90 mm diameter and 220 mm length cylinder was manufactured. The cylinder was made of PVC material and used some filler to make it structurally rigid. The cylinder was vertically supported on a six component sensor (type JR3) that had a sensitivity of 0.05% over a range of 0 to 200 N. For more details of this method can be found in Chowdhury et al. [12, 13]. The aerodynamic forces and their moments were measured for a range of Reynolds numbers (Re) based on cylinder diameter and varied wind tunnel air speeds (from 30 km/h to 140 km/h with an increment of 10 km/h). Each test was conducted as a function of swimsuit's fabric tensions.

2.2 Description of Fabric Tension Measurement

An Instron Machine 4466 was used to conduct the tensile strength test. Two adapters (grips made of Aluminum) were designed to hold the two ends of fabric uniformly. One attachment was used for the upper end of the textile connected to the moving part of Instron loading arm while the other attachment was used to hold the base. The maximum capacity of the used Instron machine was 10,000 N of tensile force. The rubber slabs were used on the interior side of the Aluminum adapter pales to make sure that the fabric would not slab out of the grip. The dimensions of the plate are 250 mm × 60 mm × 10 mm which is bigger than the sample. Three samples of Diana swimsuit material were prepared. The dimensions of the sample are 220 mm × 280 mm × 0.27 mm. The experimental setup using Instron along with the sample under various tensions are shown in Figure 2.



(a) Un-stretched fabric test (no force apply)
(b)

(b) Stretched fabric test (maximum force apply)

Fig 2. Fabric tension measurement setup in RMIT lab

Figure 3 shows the results for tension measurements of the fabric sample used in this study. The fabric sample was stretched till it reached 100 mm extension from zero. The data measurement sampling rate was 4 Hz. It may be noted that the extension was measured in the lateral direction of the fabric material as in situ situation generally the extension of the swimsuit fabric is allowed laterally.

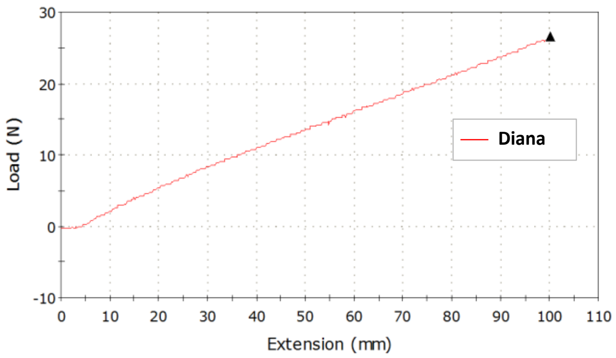


Fig 3. Fabric extension versus tensile load

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 4. 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 JR3 multi-axis load cell, also commonly known as a 6 degree-of-freedom force-torque sensor made by JR3, 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 four times 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. More details about the wind tunnel can be found in Alam et al. [15].

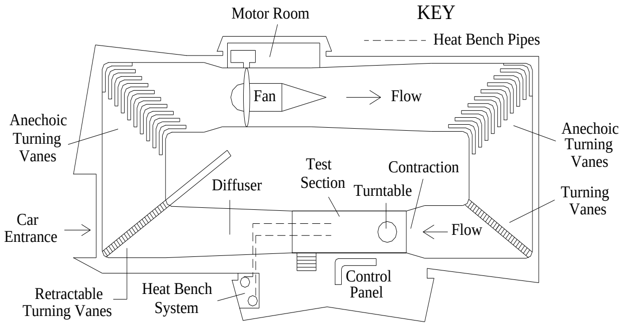


Fig 4. A plan view of RMIT Industrial Wind Tunnel [15]

The bare cylinder was tested initially in order to benchmark the aerodynamic properties with the published data. The bare cylinder test setup is shown in Figure 5. Then, the cylinder was wrapped with varied tensioned swimsuit fabrics to measure their aerodynamic forces and moments. More details about the end effects of the bare cylinder (3D effects) can be found in Chowdhury et al. [12].

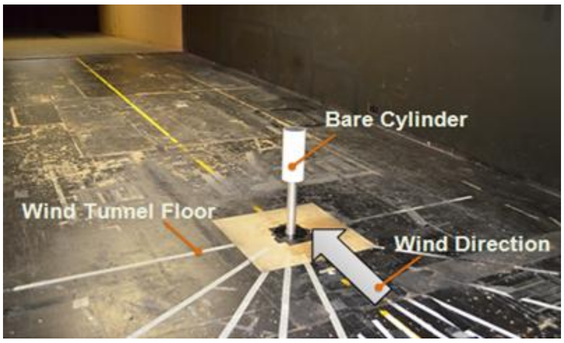


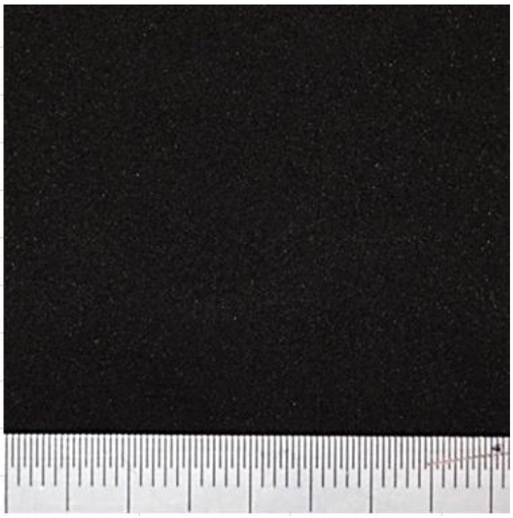
Fig 5. Experimental bare cylinders set up in RMIT Industrial Wind Tunnel

2.4 Microstructure Analysis of Diana Submarine Swimsuit Fabric

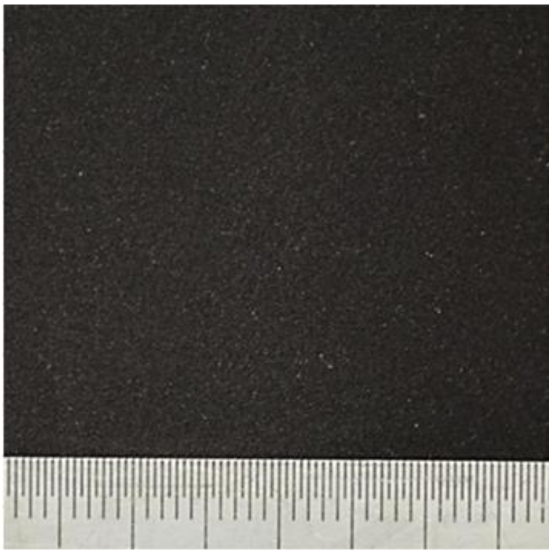
A brand new of Diana Submarine swimsuit material has been selected for this study. It is made of 66% Nylon and 34% Lycra. The optical images (no magnification) do not show a notable difference in the fabric surface profile under tension (see Figure 6 a, b & c). However, the fabric under tension is more transparent than the fabric with no tension (see Figure 2).

The optical images (5 times magnification) show a slight difference between the tensioned fabric as shown in Figure 7 a, b & c. All tensioned images were shown at the same length scale. As the tension applied in lateral way, 27 bundles can be seen in un-stretched case. With applying force of tension, the number of bundles within the same length scale was reduced to 22 and 19 bundles at 60 mm and 100 mm extension respectively.

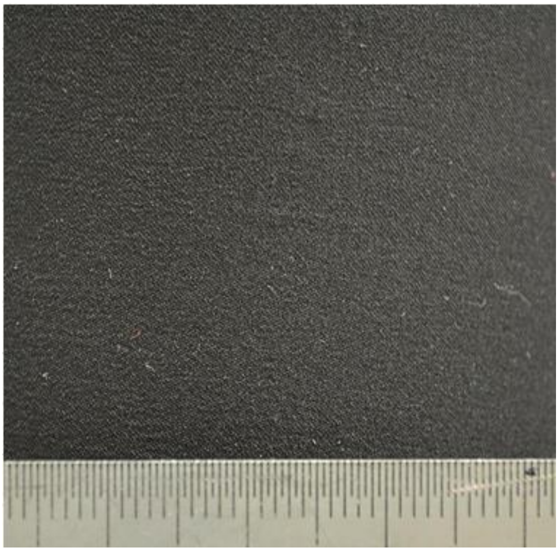
In order to study the fabric microstructure, an Electron microscope was used to illustrate the fabric features at 100 and 2000 times magnification for the stretched and un-stretched fabrics as shown in Figures 8 & 9. Figure 8 a & b shows a notable difference in the stretched and un-stretched fabrics. As shown in Figure 9 the fiber diameter is approximately 19.64 μm.



(a) 0 mm extension

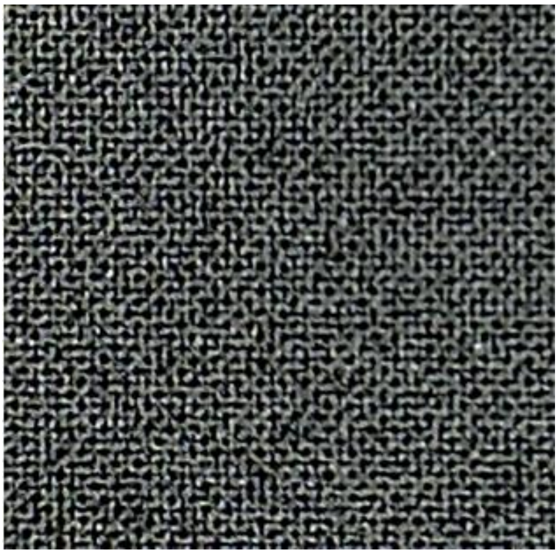


(b) 60 mm extension

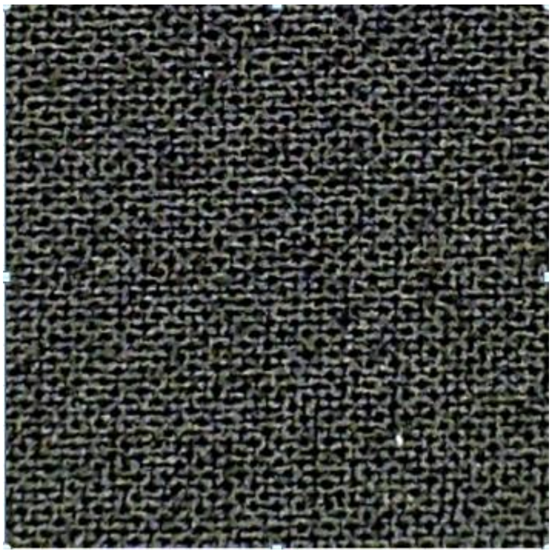


(c) 100 mm extension

Fig 6. Combined optical images for stretched and un-stretched fabric (no magnification)



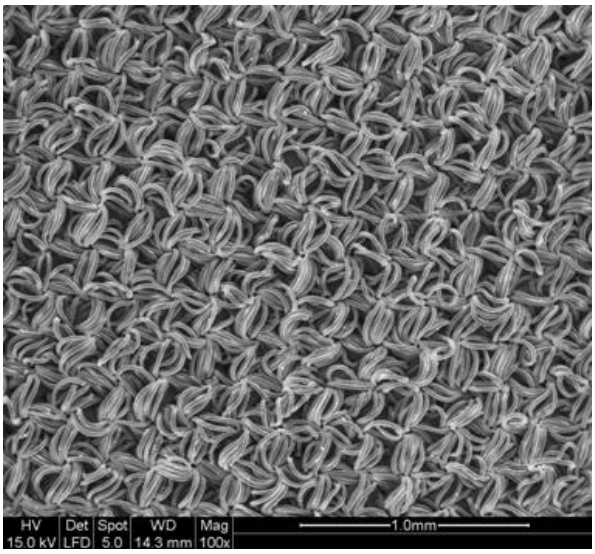
(a) 27 Bundles in lateral line for 0 mm extension



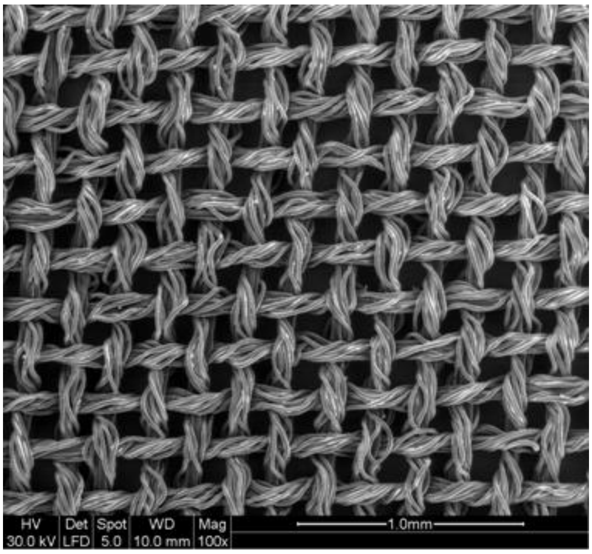
(b) 22 Bundles in lateral line for 60 mm extension

(c) 19 Bundles in lateral line for 100 mm extension

Fig 7. Combined optical images for stretched and un-stretched fabric (5 times magnification)



(a) Un-stretched fabric (no tension)



(a) Stretched fabric (under tension)

Fig 8. Surface profile using an Electron microscope (100 times magnification)

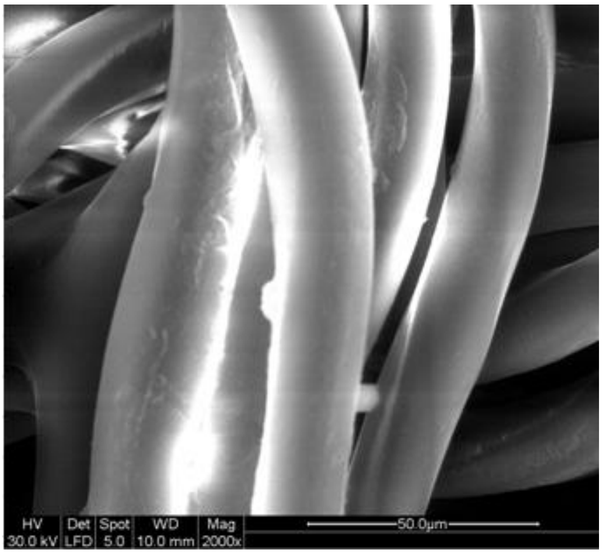


Fig 9. Surface profile using an Electron microscope (2000 times magnification)

3. RESULTS AND DISCUSSION

As mentioned earlier, the purpose of studying different fabrics under tension is to measure the effect of aerodynamic properties. Hence, 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:

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 A} \tag{3}$$

The drag force (D) versus wind speed (V) and the drag coefficient (C_D) as a function of Reynolds numbers (Re) for a range of tensioned fabrics are presented in Figures 10 to 11. In order to compare the results of swimsuit (stretched and un-stretched fabrics), the drag force (D) and C_D for the bare cylinder were also shown in all figures. Figures 10 shows that the drag for the bare cylinder (without fabric) is continuously increasing without any abrupt changes as expected. Similarity, the drag force of the fabric with no tension is continuously increasing as the bare cylinder. However, the magnitude of drag force is lower compared to the bare cylinder. In contrast, the drag forces for the fabrics under various tensions have sudden drop in magnitude at different speeds are noted.

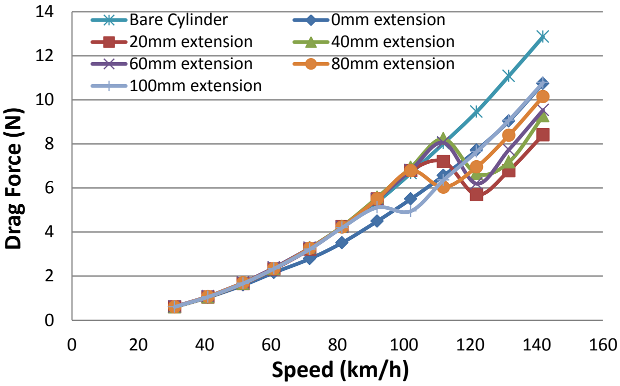


Fig. 10. Drag variation with speeds

The C_D variations with Re as shown in Figure 11 clearly indicate that the swimsuit fabrics have undergone the flow transition from laminar to turbulent flow regimes at different range of speeds. The 0 mm extension (normal fit), has undergone early transition at 30 km/h (e.g., Re= 5.08×10^4) compare to other cases. On the other hand, the maximum tension tested in this study delays the transition from laminar to turbulent flow regimes compared other fabrics under tension. However, the 0 mm and 100 mm extension have the same C_D at high speed. The fabric tension with 40 mm and 60 mm extension delays the flow transition significantly later (transition starts at 110 km/h and ends at 130 km/h for 40 mm extension and start at 110 km/h and end at 120 km/h for 60 mm extension). However, once the transition occurs, the C_D values become significantly lower. Among all fabric samples under tension, the 20 mm extension has the lowest C_D value (transition occurs at 100 km/h) compared to other two samples with 40 and 60 mm extension. In general, the rougher surface of the swimsuit fabric 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. In addition, the seam position also plays a notable role in flow transition. However, it was addressed in this paper. More about the seam effects can be found in Moria et al. [14].

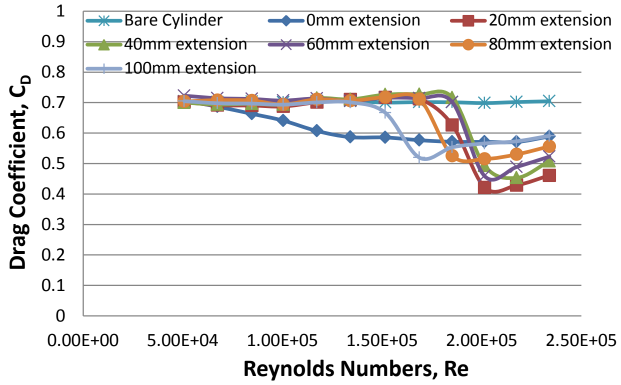


Fig. 11. C_D variation with Re

4. CONCLUSIONS

The following conclusions were made based on the experimental study presented here:

- The surface structure with varied stretched and un-stretched fabrics has a notable effect on the aero/hydrodynamic drag.
- Diana fabric under lower extension (20 mm) has relatively better advantage due to lower C_D value.
- The fabrics under moderate and higher tensions (40, 60 and 80 mm extensions) also have aerodynamic advantages at higher Reynolds numbers.
- The flow transition can be controlled by fabric surface profiles in order to minimize the aerodynamic drag.
- The normal fit fabric (no extension) had an early flow transition thereby can be beneficial at lower Reynolds number.

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7. NOMENCLATURE

Symbol	Meaning	Unit
Re	Reynolds Number	
C_D	Drag Coefficient	
D	Drag Force	(N)
ρ	Fluid 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)
l	Characteristic Length	(m)
g	Gravitational Acceleration	(m/s^2)

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