Dept. of Mech. Eng.
CUET

Mechanical Engineering Research Journal

Vol. 9, pp. 110–114, 2013

ISSN: 1990-5491

AN EXPERIMENTAL STUDY ON SPEED SKATING SKINSUITS

H. Chowdhury*, K. Naito and F. Alam

School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Melbourne, 3001,
Australia

Abstract: This paper investigates the aerodynamic behaviour of four commercially made skinsuits of various surface morphology widely used in speed skating. The aerodynamic properties of each skinsuit were studied over a range of wind speeds in a wind tunnel environment. A standard cylindrical methodology was used to quantify aerodynamic drag forces acting on each skinsuit fabric. Roughness height of each fabric was also qualified including their microstructures using electron scanning microscope. The experimental data indicated that surface structure of the skinsuits has significant effect on aerodynamic drag. A correlation was established among the aerodynamic drag coefficients, surface microstructure and average surface roughness of fabrics used in speed skating skinsuits.

Keywords: *Aerodynamics, speed skating, skinsuit, wind tunnel, aerodynamic drag*

1. INTRODUCTION

Aerodynamic efficiency plays an important role in speed sports as it governs not only athletes' speed but also their energy expenditure during the competition. In addition to athlete's body position and equipment, the surface morphology of skinsuit can play a vital part in reduction of aerodynamic resistance. In competitive sports, every moment is important and counted. Professional skaters attempt to utilize every possible legal means to enhance their performance. Using modern skinsuits, skaters endeavor to reduce hydrodynamic drag thereby get competitive advantage.

Kuper and Sterken [1] investigated aerodynamic contributions of specific speed skating skinsuits. The Nike Swift Skin suit, the Hunter Delta-Flash suit and the Descente Vortex C2 suit, which were popularly worn at the 2002 Winter Olympics, were compared in regards to winning times. The study concluded that the Nike Swift Skin suit would lead to reducing 0.2-0.3 second per lap, which is a significant margin for a high speed sport like speed skating.

Sætran and Oggiano [2] tested six different skinsuits with different surface roughness. Through wind tunnel testing and mathematical modelling, Sætran and Oggiano (2008) justified that skinsuits do affect speed skaters' performance. The largest hypothetical time difference amongst the six skinsuits over the distance of 1500 m was estimated as 3 seconds. During the study, it was discovered that the roughness of the fabric that is used for legs exerted the most significant effect to the overall performance of skaters. The study ultimately indicated that fabric selection for the legs needs to be sensitively made. As per the study, increasing the roughness of the skinsuit helps reduce drag at low speed. However increasing roughness leads to an elevation in drag at high speed. Sætran and Oggiano [2] concluded that a rough fabric pattern on the legs is desirable for female skaters and for long distance races while a smoother pattern is advantageous for men's short distance events. It was also mentioned that the use of extremely smooth or rough textiles is not recommended as both types of the textiles would cause high drag in speed skating.

Brownlie and Kyle [3] introduced the evolution of Nike's SWIFT Skinsuit. The research states that the first model of the SWIFT series, which was developed for the 2002 Winter Olympics, provided a 10.1% reduction in drag and helped the competitors perform 1.03% better than their previous personal records. As evidence, it outperformed the design from foreign manufacturers; skaters, who wore the SWIFT Skinsuit, won 16 medals of a possible 30 medals. Such a success caused foreign skinsuit manufacturers to incorporate the features of the SWIFT

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[*] **Corresponding author:** Email: harun.chowdhury@rmit.edu.au; Tel: 61 3 99256103; Fax: 61 3 99256108

Skinsuit such as rough fabric patterns on the arms and legs and smooth polyurethane coated on the torso and thighs [2]. Despite some modifications were made to the SWIFT Skinsuits for the 2006 and 2010 Winter Olympics, the similarity in fabric features led awarding medals more evenly than the 2002 Olympics.

The fabric surface morphology is important in many respects. It may constrict the athlete’s body so as to reduce the apparent roughness of the natural body shape. The surface roughness is an important parameter because it can change the boundary layer state from laminar to turbulent, thus reducing the overall drag of the skaters. Despite of several studies on various commercial speed skating skinsuits for their aerodynamic performance, scant or no information can be found on the correlation between the surface morphology and aerodynamic drag of various fabrics. Therefore, the main objective of this study was to understand the effect of surface morphology of various skinsuits on the aerodynamic behaviour.urban structures and buildings.

2. MATERIALS AND METHODS

2.1 Fabric Materials

Four different types of skinsuits were selected for this study. The suits were made by different manufacturers. Table 1 shows the list of the suits.

Table 1 Four skinsuits used in this study

Skinsuit	Manufacturer
SWIFT Sprint Skinsuit	Nike
SkateNow LT Skin Suit	Hunter
Adulte Long Track Skin Suit	Louis Garneau
LT Skin Suit 100% Lycra	Bont

As per Sætran and Oggiano [2], fabrics, used for the legs, are especially important. Therefore, the main focus of the wind tunnel tests was on the leg section.

Fig. 1: Four skinsuits used for this study: (a) Nike, (b) Hunter, (c) Louis Garneau (d) Bont.

2.2 Wind Tunnel Testing

Standard cylinder with a 110 mm diameter and 200 mm length were used in this study. Textile sleeves were fabricated for the cylinder such that each fabric had similar tensions when installed on the cylinder. Fig. 2 illustrates the setup in the wind tunnel. The cylinder was made of solid PVC for structural rigidity. Further details about the macro scale can be found in Chowdhury [4] and Moria et al. [5].

The fabric, used for the leg, was cut into a 220 mm ×220 mm square sample. Each sample was applied to the surface of the test cylinder with double-sided tape. Near the rim was reinforced by tape. The tape was applied in such a way that 3 mm is exposed to the flow so that its effect on the overall aerodynamic behaviour would be very insignificant (See Fig. 3).

The RMIT Industrial Wind Tunnel was used for this experimental study. The tunnel is a closed return circuit wind tunnel. The maximum speed of the tunnel is approximately 145 km/h. The rectangular test section dimensions are 3 meters wide, 2 meters high and 9 meters long, and the tunnel’s cross sectional

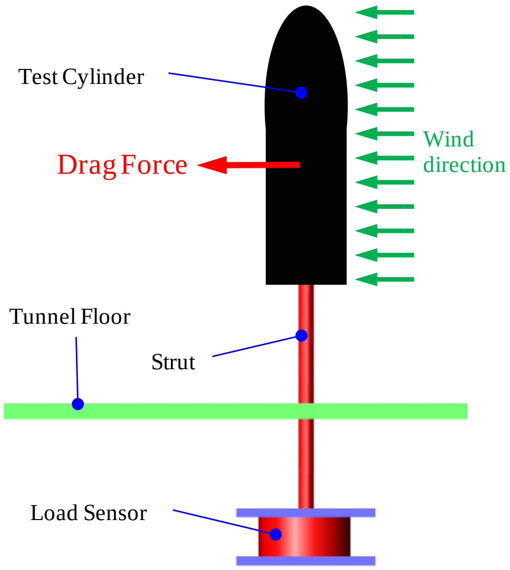

Fig. 2: Schematic of the experimental setup.

area is 6 square meters. More details of the wind tunnel can be found in Chowdhury [4]. The tunnel was calibrated prior 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 with the Baratron® pressure sensor made by MKS Instruments, USA.

The setup was positioned at the middle of the wind tunnel test section and fixed properly on top of the wind tunnel floor to minimize vibration which may cause measurement errors. The setup was positioned 150 mm above the tunnel floor to minimize boundary layer effect. Fig. 4 shows the experimental setup inside the RMIT Industrial Wind Tunnel.

Fig. 3: Test cylinder fitted with fabric sample.

The test cylinder was connected through a mounting sting with the force sensor (model: 100M40, manufactured by JR3 Inc., USA) which was fixed properly with the ground. Fig. 1 shows the schematic of the experimental setup.

Tests were conducted at a range of wind speeds (20 km/h to 120 km/h with an increment of 10 km/h) under four 90º angle of attack. The force sensor has the maximum capacity of 200 N with 0.01% accuracy. Data logging software supplied by the sensor manufacturer was used to log the data (i.e., speed and torque). Each measurement was taken three times for each configuration and wind speed tested and the average values were presented in this study. In this paper, only drag force data and its dimensionless quantity drag coefficient (C_D) are presented. The C_D was calculated by using the following formula:

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

where, D, V, ρ and A are the drag, wind speed, air density and cylinder's projected frontal area respectively. Also another dimensionless quantity the Reynolds number (Re) is defined as:

$$\mathrm{Re} = \rho V d / \mu \quad (2)$$

where, d and μ are the diameter of the cylinder and absolute air viscosity respectively.

Fig. 4: Experimental setup in RMIT Industrial Wind Tunnel.

2.3 Microscopic Imaging

FEI Quanta 200 ESEM at Applied Sciences Department of RMIT University was used to observe the fabric properties of the skinsuits at the microscopic level. The leg sleeve of each skinsuit was cut into a square sample of 10 mm × 10 mm. The samples were stretched by tweezers to the best of their ability and were fixed by vinyl tape and immediately inserted into the chamber to prevent them from returning to the unstretched state. Some samples were more resistant to lateral deformation than others. Since fabrics are not electrically conductive, the samples were cleaned and then carbon-coated, prior to being mounted in the vacuum chamber. They were examined at magnifications of 100x at 15keV in the low vacuum operational mode. The output images (1024 × 943 pixels in TIF format) were taken using computer software.

3. RESULTS AND DISCUSSION

3.1 Physical Properties of Fabrics

As mentioned earlier, the surface roughness of skinsuit materials can play a significant role in the optimization of drag. In general, for streamlined bodies, the drag increases with increasing surface roughness. However, for bluff bodies such as a circular cylinder or sphere, an increase in surface roughness can cause a decrease in the drag. In this case, at a critical value of C_D, the boundary layer of a smooth cylinder transitions from laminar to turbulent. The turbulent flow possesses more momentum than the laminar flow and thus, the flow stays attached longer and wake region behind the cylinder becomes considerably narrower. The result is a considerable drop in pressure drag with a slight increase in friction drag, combining to give a smaller overall drag and C_D. The critical Reynolds number can be reduced by tripping the boundary layer by using a rough surface. In the case of textile fabrics, the roughness depends on the fabrics microstructure. The microstructure is characterized by the fibre physical dimension, orientation, crimp or curl, porosity, thickness, and tightness or openness, etc. In order to understand the macro-structural behaviour of various swimsuit materials, an electron microscopic analysis was conducted. Electron microscope images at 100x magnification are illustrated in Fig. 5. The figure shows the fibre orientation, curl, porosity, thickness, tightness or openness and fibre bundles of surface structures for all skinsuits fabrics. In order to complement the microstructural analysis of the fabric surfaces, the KES-FB4 Automatic Surface Tester was used to determine the surface roughness of the four skinsuits. The skinsuits were stretched up to 30 mm in the course direction. Table 2 shows the measurements for each fabric sample tested. The data indicate that Nike is the roughest among all sample tested. On the other hand, the surface roughness of the Hunter fabric is relatively rougher than any other suit fabrics.

Table 2 Average surface roughness data

Fabric sample	Roughness [μm]
Nike	9.45 ± 0.40
Hunter	3.99 ± 0.21
Louis Garneau	7.31 ± 0.34
Bont	6.09 ± 0.33

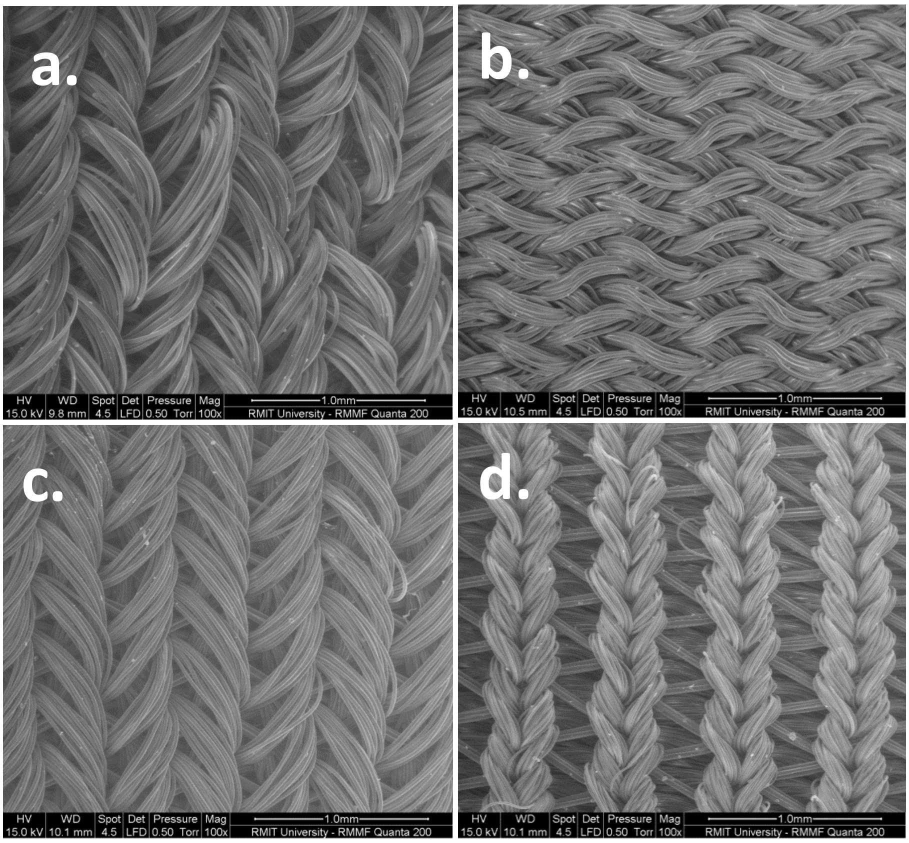

Fig. 5: SEM images (100x magnifications) of fabric materials: (a) Nike, (b) Hunter, (c) Louis Garneau (d) Bont.

3.2 Aerodynamic Results

The C_D values for all 4 skinsuit fabrics are shown in Fig. 6 as a function of *Re*. For comparison purpose, the C_D values of the bare cylinder are also presented in the figure.

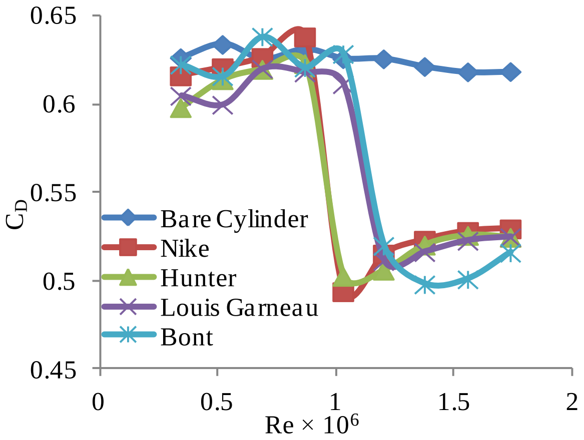

Fig. 6: C_D variation with *Re* for swimsuit fabrics.

The surface roughness has significant effect on the air flow characteristics over the surface. The data indicates the early transition for the Hunter and Nike fabric at $Re = 0.8\times10^6$ despite of their differing roughness value. But Louis Garneau and Bont, relatively smooth fabrics compared to Nike, undergoes a late transition at $Re = 1.0\times10^6$. The results show that all fabrics underwent transition between 50 to 60 km/h, however, their minimum C_D values are different. Nike shows min C_D (0.49) at 50 km/h. On the other hand, Bont exhibits min C_D than other fabrics at relatively higher speed (above 80 km/h). At 100 km/h wind speeds all fabrics shows similar C_D values with minimum variations. Nevertheless, based on required *Re* range, an optimal utilization of various skinsuit fabrics with different roughness can be used to gain the advantage for the speed skaters.

4. CONCLUSIONS

The flow transition can be manipulated for gaining aerodynamic advantages by using an optimal surface roughness of the fabric material. The surface morphology can be directly related to the aerodynamic drag.

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