Abstract

Aerodynamics play a significant role in high performance textiles across a wide range of sports including cycling, skiing, bobsleigh, sprint, and speed skating. Considerations in this aerodynamic performance include the textile surface morphology, fastener placement and air permeability. Elite competition usually involves very short winning time margins in events that often have much longer timescales, making aerodynamic resistance and its associated energy loss during the event significant in the outcome. This paper describes the impact of textile surface employing a standard cylindrical arrangement in wind tunnel studies to provide data on aerodynamic drag and lift as a function of athlete’s body positions together with textile surface morphology.

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Keywords: Aerodynamics, drag, lift, textile, fabrics, sports;

1. Introduction

The use of textile materials in high performance sports can play a pivotal role in the outcome of the event and/or game. It is no doubt that the understanding of aerodynamic effects of sports garments on sporting performance is becoming an important criterion of sports technology and product design. The demands on garment design associated with the aerodynamics require a quantitative understanding of materials performance, textile construction and surface texture [1, 2, 3, 5, 6]. Therefore, the garment design requires detailed information on the textile and surface morphology as well as systematic evaluation of the aerodynamic behaviour using wind tunnel experimentation and/or Computational Fluid Dynamics (CFD) modelling. Since the early work of Kyle [3] and Brownlie [4] in the 1980s and more recently studies by Chowdhury et al [1, 2, 3] on the aerodynamic effects of sport clothing, systematic progress has resulted in aerodynamic apparel being associated with success at the highest elite levels for example, in sprint running, speed skating, cycling and ski jumping as they reported more recently. Considerations in this aerodynamic performance include the textile weave or knit, seam and fastener placement and air permeability. Elite competition usually involves very short winning time margins in events that often have much longer timescales, making aerodynamic resistance during the event significant in the outcome. There have been a
series of research studies [4, 5, 7, 8] over the last two decades progressively identifying reductions of aerodynamic drag in sports garments.

Prior studies [4, 5, 7] were primarily carried out in wind tunnels utilizing mainly mannequins with athletic apparel and cloth covered. Recently, Chowdhury [8] has extensively reviewed the factors that influence performance where aerodynamic resistance was considered in terms of athlete body position.

As mentioned earlier in all high performance sports, the body position plays an important role as some body parts are responsible for generating either pure aerodynamic resistance (drag) or both drag and lift simultaneously. Depending on angle of attack, the aerodynamic drag and lift can be manipulated. This manipulation can be significantly enhanced using textile morphology especially varying fibre orientation, compressibility, seam and zipper placement. These surface features can potentially exhibit subtle yet significant influences on drag, lift forces and flow transitions. Surface roughness is an important parameter for lift and drag due to the transitional properties at the boundary layer. In this work, we report an experimental wind tunnel arrangement that provides information on the aerodynamic drag and lift characteristics of a series of sports textiles covering a standardized cylindrical geometry able to be deployed at various angles of attack.

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Description</th>
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<tbody>
<tr>
<td>D</td>
<td>Drag Force</td>
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<td>L</td>
<td>Lift Force</td>
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<tr>
<td>CD</td>
<td>Drag Coefficient</td>
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<tr>
<td>CL</td>
<td>Lift Coefficient</td>
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<tr>
<td>Re</td>
<td>Reynolds Number</td>
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<tr>
<td>V</td>
<td>Velocity of Air</td>
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<tr>
<td>ν</td>
<td>Kinematic Viscosity of Air</td>
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<td>ρ</td>
<td>Density of Air</td>
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<tr>
<td>A</td>
<td>Projected Area</td>
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<tr>
<td>α</td>
<td>Angle of Attack</td>
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<tr>
<td>θ</td>
<td>Angle of Rotation</td>
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2. Experimental Procedure

2.1. Athlete’s Body Position

The body configuration of human is extremely complex due to varied shapes and size. In a simple way, these body parts can be represented as multiple cylinders. Thus, the aerodynamic characteristics of these cylindrical body parts can easily be evaluated in wind tunnel testing under range of angles of attacks representing real life body position in sporting actions. In order to simplify the complex interaction of various body parts on aerodynamic properties, a simplified cylindrical geometry was used to generalize the findings. The effects of body parts being in close proximity to each other using simplified cylinders were studied by Chowdhury et al. [1, 3].

As mentioned earlier, these body parts covered with textiles can influence the aerodynamic behaviour by altering the transition from laminar to turbulent boundary layer of the flow without affecting the body position. The aerodynamic transition can also be influenced by varying angle of attacks. A decomposition of athlete’s body position in some sports is shown in Fig. 1. A sprinter’s body representation is shown in Figure 1(b). Similarly, Figures 1(c) and 1(d) show the body decomposition of a cyclist and ski jumper respectively. The breakdown of individual body parts clearly show that these parts can be treated as multiple cylinders with varied dimensions and positions (angle of attack from 0 deg to 180 deg). In order to evaluate aerodynamic properties (drag and lift forces
and their corresponding moments) of these cylindrical body parts under a range of positions, a wind tunnel experimental methodology has been developed. More details about the methodology and experimental set up can be found in Chowdhury et al. [3].

Fig. 1. Athlete’s body position analysis

(a) Human body configuration
(b) Running athlete (Sprinter)
(c) Cyclist
(d) Ski jumper

2.2. Wind Tunnel Testing

The RMIT Industrial Wind Tunnel was used for the experimental evaluation of aerodynamic properties of various cylindrical arrangements. In each arrangement, the cylinder was tested first without any textile covered and then with textiles covered (wrapped onto it). This is a closed return circuit with a maximum air speed of approximately 150 km/h with a rectangular test section (3 m wide x 2 m high x 9 m long). The test section has a
turntable to yaw suitably sized objects. More details about the tunnel can be found in Alam et al. [8]. The tunnel was calibrated before conducting experiments. The air speeds were measured via a modified NPL ellipsoidal head Pitot-static tube (located at the entry of the test section) connected to a MKS Baratron pressure sensor through flexible tubing. Purpose made computer software was used to compute drag and lift forces and their moments. The measured aerodynamic forces were converted to non-dimensional drag coefficient (CD) and the lift coefficient (CL), using the formula as defined in Eqs. 1 and 2.

\[
C_D = \frac{D}{\frac{1}{2} \rho V^2 A}
\]

(1)

\[
C_L = \frac{L}{\frac{1}{2} \rho V^2 A}
\]

(2)

A cylindrical body geometry was developed to evaluate textile features such as seam position, fibre orientation and surface roughness [1]. The surface of the cylinder was very smooth. The cylinder can simulate any body position as shown in Figure 2 in the wind tunnel test section for the simultaneous measurements of drag and lift under any angle of attack. Suitable textile sleeves were made and wrapped against the cylinder with appropriate tensions and allowances experienced by the athletes during their sporting actions. The cylinder had a diameter and length of 110 mm and 300 mm respectively, while the 6-axis force transducer (type JR-3) had a sensitivity of 0.05% over a range of 0 to 200 N. To examine the impact of non-vertical athlete body positions which can generate aerodynamic drag and lift force, the lower section the cylinder arrangement was designed to provide a rotating mechanism to allow the cylinder to fix any angle from 0º to 180º relative to the wind direction as shown in Figure 2(a) and also the yawing can be done by using rotating table that allows the cylinder to be rotated and fixed at any angle from 00 to 3600 as indicated in Figure 2(b).

(a) Side view  (b) Top view on the turntable

Fig. 2. Standard cylinder arrangement for wind tunnel studies

3. Results

The aerodynamic properties such as drag and lift forces were measured for a range of wind speeds (20 km/h to 120 km/h with an increment of 10 km/h) under three different settings of angle of attack (α=30º, 60º and 90º from horizontal axis). Four commercially available sports textiles with varied surface topology were studied. Two textiles: Sample-1 and Sample-2 have relatively rough surfaces compared to other two textiles: Sample-3 and Sample-4. More details about these textile materials can be found in Chowdhury et al. [2]. The aerodynamic properties of the bare cylinder were measured first initially for benchmarking and hereafter, the properties of all 4 textile samples were measured with the same conditions.
Fig. 3. Aerodynamic drag for bare cylinder and 4 different fabrics at $\alpha=90^\circ$

Fig. 4. Aerodynamic drag and lift at $\alpha=60^\circ$ and $\alpha=30^\circ$

The drag coefficients for a smooth cylinder (without sleeve) and all four textiles are plotted against the speeds under three different angles of attacks ($\alpha=90^\circ$, $60^\circ$ and $30^\circ$) from horizontal which are shown in Figures 3, 4(a) and 4(c) respectively. The figures indicate that the airflow around the smooth cylinder remains relatively laminar at speeds below 90 km/h at $\alpha=90^\circ$, 80 km/h at $\alpha=60^\circ$ and 30 km/h at $\alpha=30^\circ$. However, the laminar boundary layer much earlier undergoes transition to turbulent boundary layer for Sample-1 & Sample-2 at 40 km/h under $\alpha=90^\circ$, 30 km/h under $\alpha=60^\circ$. No notable transition was observed at $\alpha=30^\circ$ from Figure 4(c). On the contrary, the airflow around the Sample-3 & Sample-4 textiles undergoes transition much later at 70 km/h under $\alpha=90^\circ$, 60 km/h under
\( \alpha=60^\circ \) and 30 km/h under \( \alpha=30^\circ \) compared to Sample-1 & Sample-2. The bare cylinder possesses higher value at almost all speeds tested. With an increase of angle of attack, as expected, the drag coefficient increases for all textiles and the bare cylinder as shown in Figures 3, 4(a) and 4(c).

The lift coefficients against speeds for all textiles and the bare cylinder are shown in Figure 4(b) and 4(d) for \( \alpha=60^\circ \) and \( 30^\circ \) respectively. The Sample-1 & Sample-2 demonstrate more lift coefficients at high speeds (above 70 km/h under \( \alpha=60^\circ \) and 50 km/h under \( \alpha=30^\circ \)) compared to Sample-3 & Sample-4 textiles. A notable variation in lift coefficients between Sample-1 & Sample-2 was also observed at low speeds below 50 km/h at \( \alpha=60^\circ \) and at all speeds under \( \alpha=30^\circ \). A similar variation was also noted between Sample-3 & Sample-4 textiles at slightly different speeds and angle of attacks (see Figure 4).

4. Discussion

The values of \( C_D \) and \( C_L \) largely depend on the angular position and surface roughness of the fabrics. These values can be optimized by analysing the data for a specific sport. The study clearly indicates that for any sports where athletes’ speeds are less than 60 km/h can use low transition textiles (Sample-1 & Sample-2). However, a further reduction can also be possible using low transition textiles by taking into account such as correct position of seams, and fibre orientations. On the other hand, when the athlete’s speeds are significantly high (over 60 km/h) high transition textiles (Sample-3 & Sample-4) can be used. A further optimisation can also be possible by altering the seam positions and fibre orientations. If athletes’ speeds are in transition zone, it would be worthwhile to investigate further by considering other factors such as the duration of speeds and time for different body posture during the different phase of the sports.

5. Conclusions

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

- The bare smooth cylinder possesses higher aerodynamic drag at all speeds compared to rough surface textiles.
- The surface morphology plays a key role in the reduction of drag and lift.
- Right selection of textiles for athletes is utmost important for achieving aerodynamic advantages.

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References