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AERODYNAMICS OF TEXTILES FOR ELITE CYCLIST

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ABSTRACT

Aerodynamic properties play a significant role in the textiles across a wide range of sports including cycling, skiing, bobsleigh, and speed skating. 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 and its associated energy loss during the event significant in the outcome. In fact, a two fold increase in athlete velocity results in a fourfold increase in the drag force needing to be overcome. This paper describes the impact of textile surface employing a standard cylindrical arrangement in wind tunnel studies to provide precise data on aerodynamic drag and lift as a function of athlete's body positions together with garment seam placement and apply these optimized data to cycling apparel design for elite cyclist.

Keywords: Wind Tunnel Testing, Drag, Lift, Aerodynamic, Cycling, Fabric**.**

1. INTRODUCTION

The suitability of materials for sports applications, including textiles for sports garments, must meet a range of performance parameters dictated by the specific sport. As such, the minimization of detrimental effects of sports garments on sporting performance is becoming an important aspect of sports technology and product design. The demands on garment design for high performance in dynamic sports and particularly those associated with aerodynamic resistance and its associated energy loss during an event, extend the conventional design methodology of synthesis, form, and function to new requirements for quantitative understandings of materials performance, textile construction and surface texture [1]. As such, garment design and its engineering modelling requires detailed information on the textile and surface physics of the materials as well as systematic evaluation of the aerodynamic behaviour in the wind tunnel and modelling. Strangwood [2] points out that the close interplay of design and sports materials science brought about by engineering modelling is only as good as the data on which it is based. Since the early work of Kyle [3] and Brownlie [4] in the 1980s and more recently studies by Chowdhury on the aerodynamic effects of sport clothing [8, 9], systematic progress has resulted in aerodynamic apparel being associated with success at the highest elite levels in, for example, sprint running, speed skating, and cycling 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 [4]. There have been a series of research studies over the last two decades progressively identifying reductions of aerodynamic drag in sports garments [5, 7, 8].

Kyle and Brownlie [6] carrying out systematic wind tunnel studies utilizing both mannequins with athletic apparel and cloth covered cylinders, showed that cylinders could evaluate drag and flow transitions. Recently, Faria [7] and Chowdhury [8] have extensively reviewed both the exercise protocols and the factors that influence performance where aerodynamic resistance was considered in terms of both sports equipment and athlete body position [7].

The surface texture as well as garment construction, e.g. seam placement, can potentially exhibit subtle yet significant influences on drag, lift and flow transitions. Surface roughness is an important parameter for lift and drag due to the transitional properties at the boundary layer. In this paper we report an experimental wind tunnel arrangement that provides precise 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. Here, we apply these studies to aerodynamic effects encountered in time-trial cycling where medium to high velocities are achieved and resistance results in significant associated energy losses. The influence of the aerodynamic characteristics of cycling garments, fabric texture and seam placement, are given through the standard cylindrical geometry in the wind tunnel.

2. EXPERIMENTAL PROCEDURE

The aerodynamic properties, such as drag, lift, side force and their corresponding moments, of four fabrics (shown in Figure 8) were measured in the RMIT Wind Tunnel, which was a closed return circuit with a maximum air speed of approximately 150 km/h. The rectangular test section dimension is 3 m (wide) x 2 m (high) x 9 m (long) with a turntable to yaw suitably sized objects. The tunnel was calibrated before conducting experiments with air speeds 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 all 6 forces and moments (drag, side, lift forces, and yaw, pitch and roll moments) and their non-dimensional coefficients.

Figure 1 gives the 3-D CAD model used showing various segments as semi-cylindrical elements and typical athlete body angles in time-trial cycling.

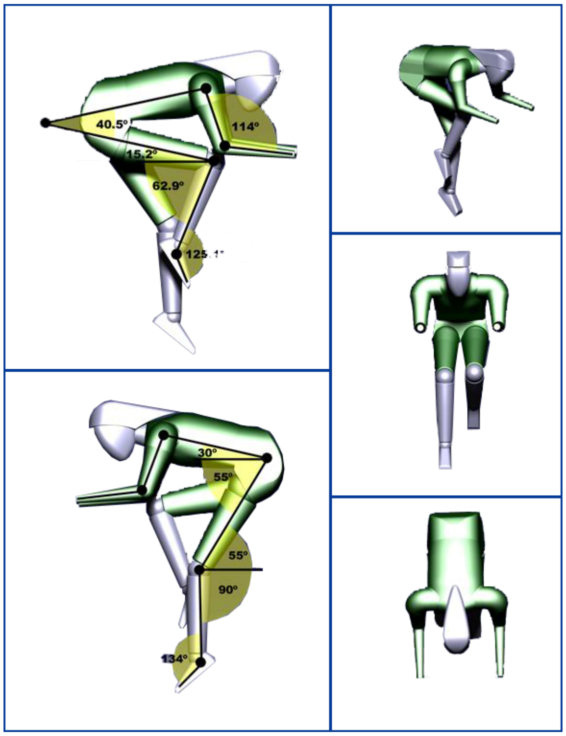

Fig 1. 3D-CAD model of typical body angles in time-trial cycling

A standard cylindrical geometry was adopted to evaluate textiles and garment features e.g. seams which consisted of an active central section (yellow) connected to the load cell and passive upper and lower sections (red) assembled to minimize end effects as shown in Figure 2, details of which are given elsewhere [7, 8]. The active cylinder has a diameter and length of 110 mm and 400 mm respectively, while the 6-axis force transducer (type JR-3) had a sensitivity of 0.05% over a range of 0 to 400 N. To examine the impact of non-vertical athlete body positions, which can generate aerodynamic drag, lift and down-force, the lower section the cylinder arrangement was designed to provide a rotating mechanism to allow the cylinder to assume any angle from 30º to 150º relative to the wind direction (Figure 2).

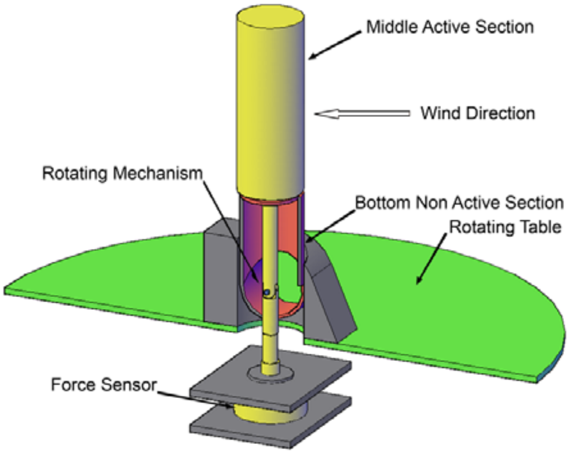

Fig 2. Standard cylindrical geometry arrangement for wind tunnel studies

Textile sleeves were fabricated for the cylinders such that each fabric had similar tensions when installed on the cylinder. The surface textures showed two length scales of features, optical microscopy showed features in the range 500 to 1000 μm and environmental scanning electron microscopy ESEM (QUANTA 200 FEI) provided resolution down to the single micron scale (see Figure 8). Bulk textile moduli (stretch) were determined for each textile using an Instron device.

3. RESULTS AND DISCUSSION

The aerodynamic properties such drag, lift and side forces were measured for a range of wind speeds (20 km/h to 120 km/h with an increment of 10 km/h) under angles of attack (30º, 60º and 90º from horizontal). Four textiles with varied surface topology were studied. Two textiles: LT-1 & LT-2 are so called low transition textiles for their relatively rough surfaces (see Figure 8a). Other two textiles: HT-1 and HT-2 are so called high transition textiles for their relatively smooth surfaces (see Figure 8b).

The aerodynamic properties of the bare cylinder were measured first initially and hereafter, the properties of all textiles (HT-1, HT-2, LT-1 & LT-2). The aerodynamic properties were converted to non-dimensional parameters such as drag coefficient (C_D), lift coefficient (C_L), side force coefficient (C_S) and their corresponding moments. Only C_D and C_L values are presented in this study.

The drag coefficients for a smooth cylinder (bare cylinder) and all four textiles are plotted against the speeds under 90º, 60º and 30º angles of attack from horizontal which are shown in Figures 3, 4 and 5 respectively. The figures indicate that the airflow around the smooth cylinder remains relatively laminar at speeds below 90 km/h at 90º angle of attack, 80 km/h at 60º angle of attack and 30 km/h at 30º angle of attack. However, the laminar boundary layer much earlier undergoes transition to turbulent boundary layer for LT-1 & LT-2 at 40 km/h under 90º angle of attack, 30 km/h under 60º angle of attack. No notable transition was observed at 30º angle of attack (see Figures 3 to 5). On the contrary, the airflow around the HT-1 & HT-2 textiles undergoes transition much later at 70 km/h under 90º angle of attack, 60 km/h under 60º angle of attack and 30 km/h under 30º angle of attack compared to LT-1 and LT-2. The bare cylinder possesses higher C_D value at almost all speeds tested. With an increase of angle of attack, as expected, the drag coefficient increases for all textiles and bare cylinder as shown in Figures 3 to 5.

The lift coefficients against speeds for all textiles and bare cylinder are shown in Figures 6 and 7 for 60º and 30º angle of attack. The LT-1 and LT-2 demonstrate more lift coefficients at high speeds (above 70 km/h under 60º angle of attack and 50 km/h under 30º angle of attack) compared to HT-1 and HT-2 textiles. A notable variation in lift coefficients between LT-1 and LT-2 was also observed at low speeds below 50 km/h at 60º angle of attack and at all speeds under 30º angle of attack. A similar variation was also noted between HT-1 and HT-2 textiles at slightly different speeds and angle of attacks (see Figures 6 and 7).

In order to take the aerodynamic advantage (eg, lower aerodynamic drag), it would be appropriate to use LT-1 and LT-2 textiles between 40 km/h to 80 km/h speeds for the body parts facing the angle of attack at around 90º, 30 km/h to 70 km/h at around 60º angle of attack and at all speeds under 30º angle of attack. On the other hand, the use of HT-1 and HT-2 will be favourable at speeds over 80 km/h at 90º and 30º angles of attack.

The LT-1 and LT-2 textiles would be better to use for generating lift at speeds over 70 km/h under 60º angle of attack and at all speeds under 30º angle of attack as shown in Figures 6 and 7.

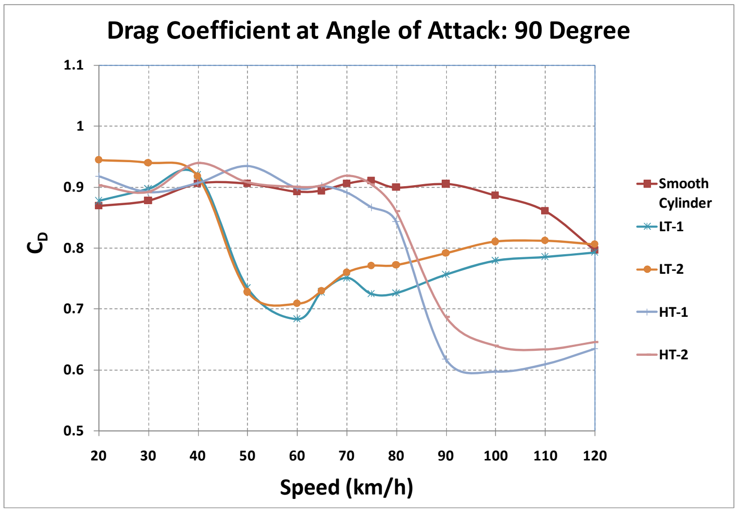

Fig 3. Drag coefficients for various textiles under the angle of attack α = 90º

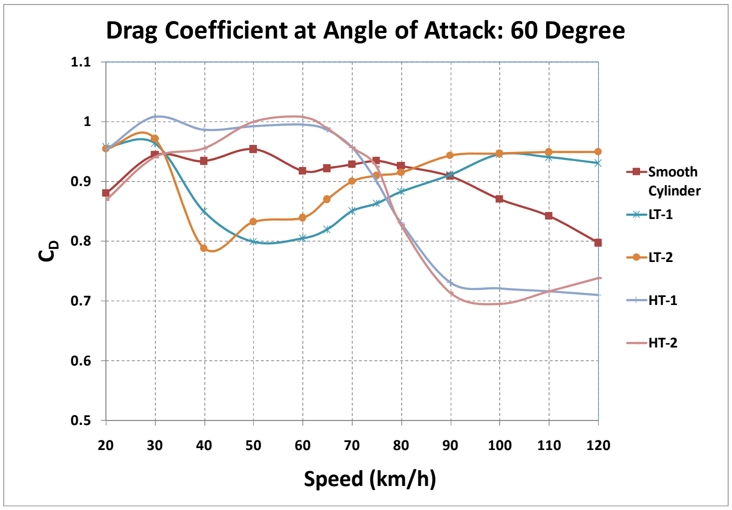

Fig 4. Drag coefficients for various textiles under the angle of attack α = 60º

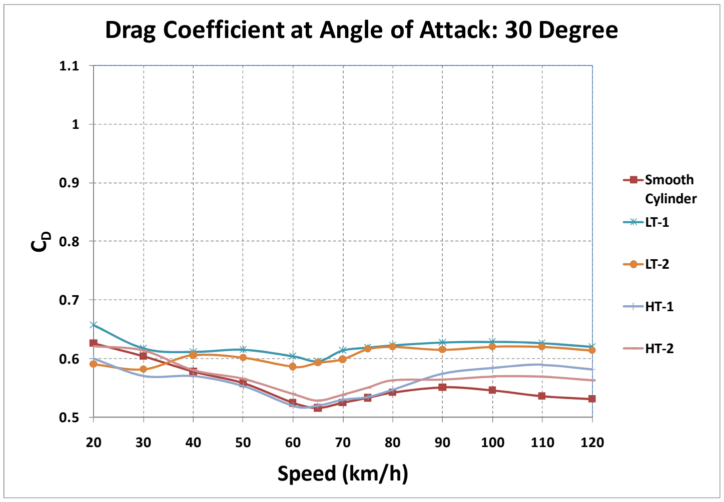

Fig 5. Drag coefficients for various textiles under the angle of attack α = 30º

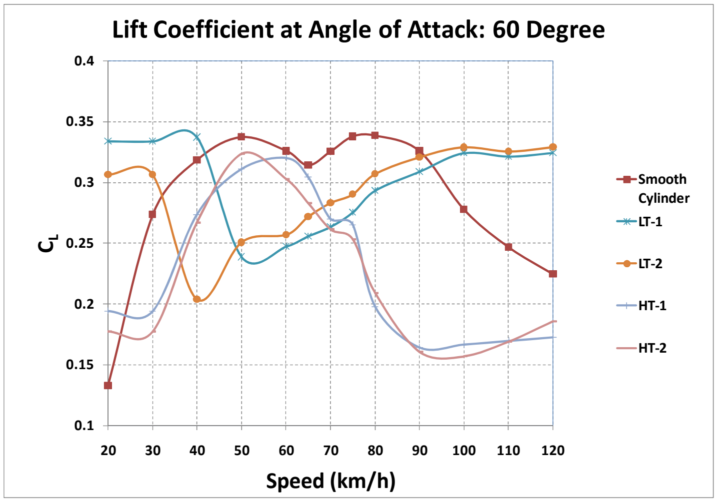

Fig 6. Lift coefficients for various textiles under the angle of attack α = 60º

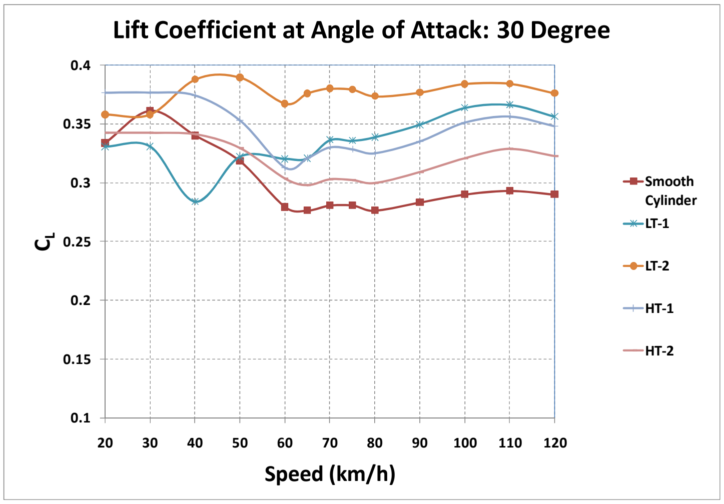

Fig 7. Lift coefficients for various textiles under the angle of attack α = 30º

Examination of the high and low transition textiles by ESEM (Figure 8) showed a marked difference in surface texture. The surface topology of the high transition samples were made up of ~600 µm linear arrays of regular yarn bundles (~250 µm) composed of fibres (~20 µm) forming the knitted fabric warp, while the low transition textiles showed weft fibres straggling the warp array decreasing isotropy and increasing surface roughness at this scale. As noted, sleeves were produced so that they provided a constant fabric tension when placed on the cylinders in order to maintain these surface characteristics.

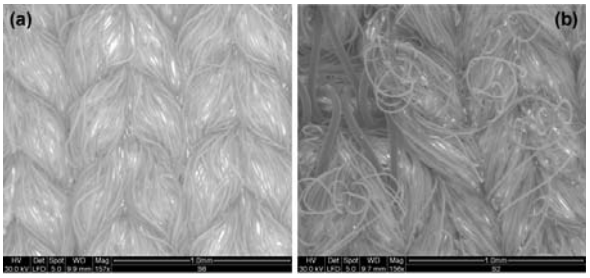

Fig 8. Scanning microscope images of high transition (a) and low transition (b) textiles (156X)

4. CONCLUDING REMARKS

The following conclusions were drawn from the work presented here:

- The bare smooth cylinder possesses higher aerodynamic drag at all speeds compared to rough surface topology 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.

5. ACKNOWLEDGEMENT

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7. NOMENCLATURE

Symbol	Meaning	Unit
D	Drag Force	(N)
L	Lift Force	(N)
C_D	Drag Coefficient	-
C_L	Lift Coefficient	-
Re	Reynolds Number	-
V	Velocity of Air	m/s
ρ	Density of Air	kg/m^3
ν	Kinematic Viscosity of Air	kg/m^3
A	Projected Area	m^2

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