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Air permeability and drag crisis on high tech fabrics for cross country ski competitions.

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Abstract

The present work aims to investigate possible improvements in cross country ski suits from an aerodynamic perspective with the main goal of evaluating if air permeability plays a significant role in the aerodynamic performances of the textiles. Three different fabrics with different surface pattern and different permeability were tested in a wind tunnel on cylinders with diameter 11cm and 16cm, for speeds ranging from 0 - 18m/s and with fabric strains from 0 - 65%. Air permeability tests were also carried out on all the different textiles for the same range of strains. Results show that significant drop in the drag coefficient can been obtained for critical wind speed (V_{CRIT}) varying between 11m/s and 17m/s depending on textile type and stretch. A clear correlation between air permeability and drag crisis was not found leading to the conclusion that the surface deformation due to the stretching plays a major role if compared with the air permeability. The results obtained show that the lowest V_{CRIT}(11 m/s) achieved in the experiments is above the relevant speeds in cross country skiing (4 - 9 m/s).

Keywords: Aerodynamics; textiles; cross coutnry skiing

1. Introduction

While sports like speed skating, downhill skiing and cycling [1-8] have been widely analyzed by researchers from an aerodynamic perspective, little focus have been previously put on aerodynamics in cross country skiing.

This despite the fact that some authors estimated the influence of drag on total energy expenditure in cross country skiing to vary between 10% and 40% . Thus there might be significant benefits in improving aerodynamics of the athletes in a cross country ski competition [9]

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Previous research carried out in textile aerodynamics aims to reduce the drag acting on the athletes by triggering the typical drag crisis that happens on bluff bodies at lower speeds modifying the surface of the textile itself. However, it has not been shown yet that the drag crisis can be triggered to speeds within the range of interest for cross country ski competitions. A closer look at the speed reached by the skiers during the races is then important in order to evaluate if there might be any advantage in using textiles that are able to trigger the drag crisis. To do that, data from the FIS World Cup (WC) of 2010 and 2011 in sprint, 15km, 10 km and marathon races (50-90 km) has been gathered. From the speed analysis the skiing speeds during cross country skiing races was found to vary in a range from 4 to 12m/s where high peak speeds are maintained only for short intervals. During short races, higher speeds were measured (from 5 – 10m/s) while for longer races like ski marathons the speed varies between 5m/s and 7m/s. Low drag textiles have been in the past investigated by a number of authors and the advantage of using a suit which is able to lower the athletes drag have been shown. Most of the authors [1-6] focused their work on the type of roughness used and how the different types of roughness are able to trigger the transition, some other authors [6, 7, 10]investigated the correlation between air permeability and roughness claiming that the air permeability plays an important role in terms of drag reduction. The present work aims to investigate if there might be sensible improvements in the cross country skiers performances focusing on the improvement of garments worn, and it has the secondary scope to verify if there is a link between air permeability, drag and roughness.

2. Methods

2.1. Wind tunnel test

The wind tunnel used for the experiments was the NTNU wind tunnel. The wind tunnel has a cross-section test area of 2.7x1.8 m, with length 11 m and a fan capable of supplying an air velocity of up to 30 m/s. A high resolution 6 component balance produced by Carl Schenk and mounted under the wind tunnel flow was used to acquire the drag.

A cylindrical model was built in order to be able to test the different textiles. However, a vertical configuration was chosen instead of a horizontal configuration due to these main reasons:

- Reduce vibrations by eliminating the arm of the supporting structure
- Ease the change of PVC-pipe (described later)
- A more practical approach to obtain an semi-infinite cylinder

The test consisted of two parts to allow easy interchangeability of PVC pipes with different diameters. The PVC pipes constitute the outer parts of the rig, upon which the tested materials were placed. The piping had two different diameters (11 cm, 16 cm) that were cut to lengths so that 30 cm was left below and above the cylinders in the wind tunnel. The core of the model was made from a 148 cm long steel tube with an outer diameter 75mm and 3 mm wall thickness that was welded to a 30x20x1cm steel base-plate. The base plate had 10 mm holes drilled in it, spaced 5cm apart to allow mounting it to a 6 component force balance inside the wind tunnel. Combined with the PVC cylinders, the rig had a total height of 150cm. The samples were mounted on cylinders with diameter 11 cm or 16 cm and tested in the wind tunnel at different wind speeds ranging from 4 to 18 m/s. Each sample was tested with five different strain parameters (from 0% to 63%). The fabric were stretched in the weft direction. Five test series with 100 samples per series were collected at each wind speed over a 10 second interval. The highest and lowest measurements were discarded while the three remaining values were averaged. The temperature [T] inside the wind tunnel was measured for each wind speed using a thermometer. The temperatures were then averaged and the air density [ρ] together with the air dynamic viscosity [μ] were calculated. Between the testing of each sample, the temperature in the wind tunnel was cooled down to about 22°C.

2.2. Air permeability test

The air permeability test was performed in the Adidas Laboratories in Portland. The tests were carried out with FX 3320 Mobile Air Permeability Tester from TEXTEST instruments. A custom made four clamps text fixture was built in order to be able to test the air permeability of each textile under the desired stretching. The air permeability was measured for weft-only strain by holding warp strain at 10% strain and stretching from 10% to 70% strain in weft direction.

2.3. Textiles used

Three different fabrics with different surface and air permeability characteristics were used in the test. The three textiles (named as T1, T2 and T3) were tested on the cylinder with five different strain values S from a minimum of 0% to a maximum of 63% where the strain value was measured as follows:
T1 is a simple knitted textile while dimples of different shapes are present on T2 and T3. T1 and T2 have a simple and smooth surface while T3 has a hairy surface. This is due to the fact that the yarn used in T3 is a textured (spun) yarn while T1 and T2 were assembled with a filament yard

Table 1. Textiles used ad structure type. The three textiles used are named T1, T2 and T3

Structure type	T1	T2	T3
Yarn type	Filament	Filament	Textured
Knit structure	Smooth	Dimpled	Dimpled

3. Results

The drag measurements were carried out for all the three samples (T1, T2 and T3) on a 11cm diameter cylinder model and on a 16cm diameter cylinder mode. The samples were stretched with 9%, 23%, 43% and 63%. For the 11cm diameter model test, the results show that, for the range of speed tested (0 - 16 m/s), the resulting drag coefficient C_D varied between 1.1-1.2 showing good agreement with the classic literature [11-15]. T1 and T2 showed a similar behavior , not reaching the transition to turbulent for the range of speed tested while T3 displayed a different behavior showing a significant reduction in C_D for speeds higher than 11m/s. This behavior for T3 could be seen for all the different stretch parameters tested with a minimum in C_D reaching approximately 0.7. The samples mounted with low strain experienced the transition to turbulence at lower speed than the samples mounted with higher strain. This behavior indicates that the surface distortion caused by the stretching clearly affect the aerodynamic properties. A higher strain “smooths” the surface of the fabric moving the critical speed closer to the critical speed for a smooth cylinder. For the 16cm diameter cylinder model, all the textiles were able to trip the transition at speeds lower than 16m/s. T1 showed a V_{CRIT} of 15m/s and T2 showed a V_{CRIT} of 13m/s while T3 showed a V_{CRIT} of 11m/s. Fig. 1 summarizes the strain effect on the aerodynamic performance of the textiles by plotting V_{CRIT} against the strain S. The trendline showed in Fig. 1b for the three textiles show that the increase of V_{CRIT} while increaseing the strain is very similar for the three textiles tested.

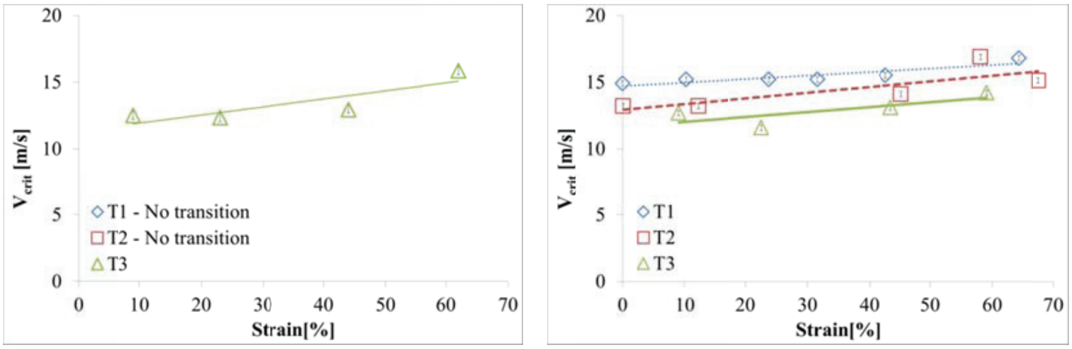

Fig. 1. (a) V_{CRIT} vs. Strain for the 11cm diameter model; (b) V_{CRIT} vs. Strain for the 11cm diameter model

No clear correlation between air permeability and the critical velocity V_{CRIT} was found for any of the samples tested. From the results presented in Fig. 3, a different behavior between the textiles can be noticed. This can be explained by the fact that aerodynamic performances and in this case the property of shifting the critical velocity are determined by other factors and air permeability doesn't affect the performances as much as the surface topology does. From Fig. 2, it can be noticed that the behavior of T2 and T3 are somewhat similar, but not to the extent that there can be drawn a conclusion based on the influence of the air permeability.

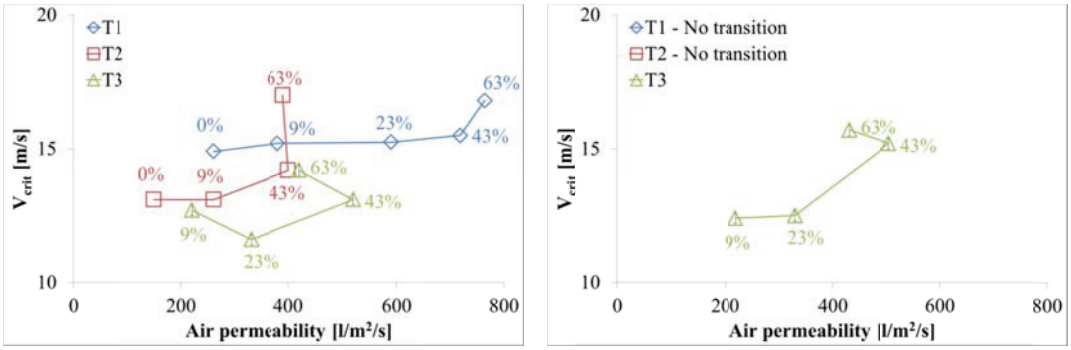

Fig. 2 (a) V_{CRIT} vs. Air Permeability for the 16cm diameter model; (b) V_{CRIT} vs. Air Permeability for the 11cm diameter model

4. Conclusions

Different fabrics were then to verify the possibility to trip the transition to turbulent regime at a range of speeds interesting for cross country ski competitions (4-9m/s). The fabrics were tested at different strains in order to evaluate the effect of both the surface topography and air permeability on the transition. On the 11 cm cylinder only the T3 sample showed a drag reduction close to the relevant speed range (11m/s). On the 16cm diameter cylinder, T2 and T1 fabrics showed drag force drops at around 13 and 15 m/s respectively while the T3 sample experienced a drop at 11 m/s. The T3 sample therefore has the greatest potential to reduce aerodynamic drag if integrated in cross country skiing suits. However, it is still at the upper limit of the speeds athletes experience during a race.

As a major couclusion, in general, the critical speed increases with increasing strain. From the limited data acquired, it can be speculatively noticed that the strain and V_{CRIT} are linearly correlated. However, more data with a larger number of strains are needed to draw a clear conclusion from this point of view. A second finding from our limited amount of data is that the correlation between strain and V_{CRIT} might be independent from the fabric surface, leading to the conclusion that for close fitting garments, surface topography has higher influence than air permeability in the process of shifting the transition to turbulent regime in the boundary layer.

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