Aerodynamics of loose sports garments

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Abstract

Ski Cross rules require loose garments and skin suits are not allowed. This study investigated the aerodynamic behaviour of flapping garments of different looseness ratios (garment length to cylinder circumference) mounted on a horizontal cylinder. Three fabrics of different roughness were tested in a wind tunnel from 20 to 140 kph. Tight fitting textiles showed the standard flow transition and critical flow regime known from smooth and rough cylinders. Flapping textiles exhibited a higher drag coefficient (on average 1.5 times higher than the tight fitting fabrics in the subcritical regime), which decreased slightly with speed. The high drag coefficient can be attributed to the flutter amplitude which increases the wake diameter and prevents backward movement of the separation points. The looseness ratio (fineness ratio) affects the drag coefficient only marginally (drag decreases with the ratios).

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1. Introduction

Ski Cross (SkiX, SX) became an Olympic Sport for the first time at the 2010 Winter Olympics in Vancouver. Although SX is a freestyle discipline, the competition is decided by speed without any judged component. Four athletes are racing against each other at any race, and the one who crosses the finish line first, wins. Thus, SX seems to be closer to alpine skiing than to freestyle; yet, the difference lies in the equipment rules. According to the SX rules [1], garments must be loose, and specifically, the gap between the leg (mid thigh to mid shank) or upper arm / elbow and the fabric must be at least 80 mm or 60 mm, respectively. The gap is measured with an SX suit measurement tool (by Settele Construction.

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Lindenberg, Germany). Aerodynamics of loose garments poses a new design challenge due to the new SX rules, as the research focus was concentrated only on tight garments (skin suits) so far.

Oggiano and Sætran [2] tested different loose garments on mannequins and cylinders and tested two parameters: thickness and roughness. For cylinder tests, they mounted garments sleeves of 408 mm circumference (corresponding to a cylinder diameter of 130 mm) on cylinders of 110 mm diameter. They claimed that “the diameter of the samples has been chosen so that the fabrics, when mounted on the models, were conforming to the FIS rules” [2]. However, mounting these garment sleeves on the cylinders results in a gap of less than 50 mm. Furthermore, Oggiano and Sætran [2] did not provide any $C_D$ (coefficient of drag) data for the garments tested, nor any comparison with tight garments.

The aim of this study was to test garments of different looseness ratios and to evaluate how different degrees of looseness influence the coefficient of drag.

2. Analysis of Looseness

In order to define the degree of looseness, we used the looseness ratio $\lambda$

$$\lambda = \frac{C_T}{C_C}$$

(1)

Where $C_C$ and $C_T$ are the circumferences of textile and cylinder, respectively. As $C_C \leq C_T$, $\lambda_{\text{min}} = 1$, which corresponds to a tight fit. There are different ways of defining the gap (Figure 1). Method 1 (Figure 1 – left column) produces equal gap width $G_1$ on one side of the cylinder. $G_1$ corresponds to half the excessive length of the garment if it covers the entire cylinder surface (Figure 1 – centre column).

$$G_1 = \frac{C_T - C_C}{2}$$

(2)

And

$$\lambda_{G_1} = \frac{2G_1 + C_C}{C_C}$$

(3)

Method 2 (Figure 1 – right column) delivers maximal gap width $G_2$, if the garment forms a triangular tail on one side of the cylinder ($G_2 > G_1$).

$$G_2 = R(\sec \theta - 1)$$

(4)

Where $R$ is the radius of the cylinder and $\theta$ is half the angle of that segment of the cylinder, which is not covered by the textile (Figure 1 – right column).

$$\theta = \cos^{-1} \left( \frac{R}{G_2 + R} \right)$$

(5)

The looseness ratio $\lambda$ results from

$$\lambda_{G_2} = \frac{\pi - \theta + \tan \theta}{\pi}$$

(6)

The fineness ratio of the flapping tail corresponds to $G_1$ or $G_2$ divided by the cylinder length and is thus proportional to $\lambda$. For upper arm diameters of 105 mm and 150 mm, and a gap of 60 mm, $\lambda_{G_1} = 1.363$
and $1.255$, and $\lambda_{G_2} = 1.258$ and $1.167$, respectively, depending on the method of gap measurement (method 1 or method 2).

![Fig. 1. Definition of gaps ($G_1$, $G_2$) of loose garments; the looseness ratios $\lambda$ are (same as tested in the wind tunnel) from top to bottom row: $\lambda = 1$, $\lambda = 1.167$, $\lambda = 1.33$, $\lambda = 1.5$.](image)

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![Fig. 2. Textiles tested; T1, T2, T3 = textile 1, 2, and 3 respectively; vertical scale bar = 20 mm; scale bar indicates wind direction.](image)

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### 3. Experimental

#### 3.1. Textiles

Three different types of textiles (Table 1) were tested: Textile 1 is the warp-knitted fabric with smooth technical back that is normally used as face in a garment (Figure 2). Textile 2, an interlock based mock mesh double jersey, was the official jersey (Figure 2) of the Australian team at the 2010 Vancouver Olympic Games, and has a slightly dimpled surface, Textile 3 was also the interlock based mock mesh
double jersey but had pronounced dimpled surface (Figure 2). All textiles were made of synthetic continuous textured filament yarns that do not create hairiness on the textile surface. The fabric properties are listed in Table 1. Surface roughness was measured with the Kawabata Evaluation System (KES-FB4, by Kato Tech, Kyoto, Japan), which cannot measure the dimple depth if the dimple diameter is smaller than the probe.

Table 1. Textile materials and properties; roughness data relevant for wind tunnel testing are indicated in bold font.

| Textile | Fibre composition, % | Mass/unit area, g/m² | Thickness, mm | Surface Roughness Mean Deviation (SMD) |
|---------|----------------------|----------------------|---------------|---------------------------------------|
| 1       | 84 nylon/16 PE       | 165                  | 0.45          | warp: 3.492, weft: 2.247             |
| 2       | 100 PE               | 235                  | 0.68          | warp: 2.945; weft: 8.142             |
| 3       | 100 PE               | 185                  | 0.60          | warp: 2.197; weft: 10.448            |

Fig. 2. Textiles tested; T1, T2, T3 = textile 1, 2, and 3 respectively; vertical scale bar = 20 mm; scale bar indicates wind direction.

2.1. Wind tunnel testing

The same experimental set-up and method as described in [3] was used (Figure 3). Textile 1 was tested in warp direction, and Textiles 2 and 3 in weft direction (Table 1, Figure 2). The garments were attached to the cylinder (diameter 220 mm) with a double sided adhesive tape at the front stagnation point, and at the top and bottom of the horizontal cylinder. Four different $\lambda$ were tested in all three fabrics (Figure 1): 1.5, 1.333, 1.167, and 1 (tight fit) between 20 and 140 kph. The $C_D$ was calculated with respect to the projected area of the cylinder.

Fig. 3. Experimental set up and flapping garment at 35 kph; the small cylinder (diameter 125 mm) and the long fabric ($\lambda = 2$) were used only for imaging purposes, in order to enhance curling of the textile upward and downward and to show how the garment separates from the cylinder surface.
3. Results

Loose garments showed considerable flutter, resulting in higher $C_D$ than tight fitting garments (Figure 4). The degree of $\lambda$ did not make much of a difference, although the data suggest that the $C_D$ drops slightly with $\lambda$ (1.167 $\leq \lambda \leq$ 1.5) at least for Textile 1. In Textiles 2 and 3, the $C_D$ also drops with wind speed. In Textile 1, however, the $C_D$ drops first and then increases slightly at higher speeds. The tight fitting garments showed the typical flow transition and a critical flow regime, with $Re_{crit}$ correlating with the roughness of the garments.

Fig. 4. Coefficient of drag $C_D$ against Reynolds number $Re$.

4. Discussion

From observations during the wind tunnel tests (Figure 3), the frequency of flutter increases with speed. The increase in $C_D$ of Textile 1 could be related to larger flutter amplitude at a specific frequency range (natural frequency). The design optimization of loose garments hinges on the amplitude of textile flutter. Oggiano and Sætran [2] tested two parameters, thickness and roughness. From their results, they concluded that thicker textiles have a higher $C_D$ on average. The term “thicker” is ambiguous and should be differentiated in thicker with larger area density and thicker with higher stiffness. Area density and stiffness have different effects on flutter of flags:

Area density: dynamic drag coefficients increase with increasing area density [4]; heavier fabrics flutter at lower frequencies [5]; heavier fabrics require higher wind speeds to initiate the flutter [5]; heavier fabrics show a faster rate of flutter increase with wind velocity [5].
Stiffness: drag decreases with increasing stiffness [5]; stiffer fabrics start to flutter at higher wind speeds [5]; stiffer fabrics exhibit high initial flutter frequency [5]; in stiffer fabrics the rate of flutter increase is the lowest [5].

Furthermore, the fineness ratio has an influence on drag of flags as well: dynamic drag coefficients increase with decreasing fineness ratios [4]; amplitude of oscillation increases with decreasing fineness ratios [4]; flutter frequency of flag increases with decreasing fineness ratios [4].

At least in Textile 1, the $C_D$ decreased with $\lambda$, which stands in contrast to the behaviour of flags (increase of drag with decreasing fineness ratio). The reason for this can be explained by the decreasing flutter amplitude of shorter textile tails, hidden behind the cylinder.

Oggiano and Saetran [2] concluded that rougher loose textiles have a lower $C_D$ than smooth loose ones. This would be certainly true for tight garments at $Re < Re_{crit}$ of a smooth surface. In loose garments, however, a flow transition at smaller $Re$ does not influence the $C_D$ as the separation points cannot move backward if the garment flutters, and if the textile even separates from the cylinder surface (Figure 3). In their mannequin tests, Oggiano and Saetran [2] nevertheless found differences between different types of garments. For pants, $\Delta Ad$ (difference in drag area) was as high as 0.03 [2]. These results are supported by wind tunnel test results of athletes in different positions and garments, conducted by Fuss and Troynikov [6]. Different tops and pants resulted in $\Delta Ad$ of 0.014 and 0.024, respectively [6].

In conclusion, the magnitude of the $C_D$ is related to the flutter amplitude, which increases the wake diameter. Higher wind speeds restrict the amplitude of flutter which is reflected in the decreasing $C_D$ with speed. Flutter amplitude can be influenced by area density, stiffness and degree of looseness, which is the focus of this study. Although there is a slight improvement in $C_D$ with lower degree of looseness $\lambda$, which is more evident in Textile 1, it does not matter much as the $C_D$ is anyway too high for looseness $\lambda$ according to the rules.

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