



# Proceedings Flow Behavior Caused by Air Permeability of Ski Jumping Suit Fabric <sup>+</sup>

# Yuki Kataoka <sup>1,\*</sup>, Hiroaki Hasegawa <sup>2</sup>, Masahide Murakami <sup>3</sup>, Kazuya Seo <sup>4</sup> and Shigeru Obayashi <sup>5</sup>

- <sup>1</sup> Department of Mechanical & Intelligent Engineering, Utsunomiya University, 7-1-2 Yoto, Utsunomiya-shi, Tochigi 321-8585, Japan
- <sup>2</sup> Department of Mechanical & Intelligent Engineering, Utsunomiya University, 7-1-2 Yoto, Utsunomiya-shi, Tochigi 321-8585, Japan; hhasegaw@cc.utsunomiya-u.ac.jp
- <sup>3</sup> Professor Emeritus, University of Tsukuba, 1-1-1 Tennoudai, Tsukuba, Ibaraki 305-8573, Japan; murakami.masahide.gm@u.tsukuba.ac.jp
- <sup>4</sup> Faculty of Science, Yamagata University, 4-12 Kojirakawa-machi, Yamagata-shi, Yamagata 990-8560, Japan; seo@e.yamagata-u.ac.jp
- <sup>5</sup> Institute of Fluid Science, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai-shi, Miyagi 980-8577, Japan; obayashi@ifs.tohoku.ac.jp
- \* Correspondence: mc196708@cc.utsunomiya-u.ac.jp; Tel.: +81-28-689-6049
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**Abstract:** The purpose of this study was to investigate the effect of the air permeability of ski jumping suit fabric on aerodynamic characteristics. In the study, four types of fabric with different air permeabilities were installed onto a fabric-clothed elliptic cylinder, and the flow behavior around its surface was investigated through wind tunnel experiments. The stall was delayed by using the fabric with higher air permeability. The air flow permeated the surface of the elliptic cylinder through the fabric for the fabric with high air permeability. This air flowed out into the separation region through the fabric again, which suppress stall. The stall characteristics for the fabric-clothed elliptic cylinder were influenced by the air permeability of the fabric. The boundary layer thickness on the outer surface and the turbulence levels of the boundary layer affected the air permeability of the fabric. The higher air permeability fabrics improved the stall characteristics.

Keywords: ski jumping suit; wind tunnel experiment; air permeability; fluid force; stall

# 1. Introduction

The improvement of aerodynamic characteristics is one of the major themes of recent studies on sportswear. In particular, in sports where speed is important, such as ski jumping, bicycle racing, and speed skating, the aerodynamic characteristics of sportswear greatly affect the outcomes of competitions in those fields.

Ski jumping is a competitive event in which various factors, such as flight distance, the posture of arms and legs, ski position during flight, and the succession of movements during landing are scored. In ski jumping competitions, competitors are ranked according to a numerical score obtained by adding up components based on distance and style. The distance score depends on the hill's K-point. The style score is calculated for jumping style, and is based on keeping the skis steady during flight, balance, optimal body position, and landing posture, and is added to the distance score. As a result, the aerodynamic characteristics of ski wear greatly affect the outcomes of ski jumping competitions. In addition, many rules are set for competition equipment in order to maintain fairness in ski jumping. There are no exceptions for suits, and there are various provisions on factors that

greatly affect aerodynamic characteristics, such as suit material, thickness, surface shape, and air permeability. Particularly, the regulation for air permeability only specifies its lower limit (a minimum of 40 L/m<sup>2</sup>/s under a water pressure of 98 Pa (10 mm Aq)) [1]. Although, in general, fabric with lower air permeability is considered to be advantageous, the relationship between air flow rate and the aerodynamic characteristics of a suit has not been fully elucidated, and further research is needed. Various studies have been conducted to improve the aerodynamic characteristics of ski jumping suits. Chowdhury et al. have studied the differences in aerodynamic characteristics when suit fit and the surface shape of the fabric are changed [2,3]. However, no studies have been conducted on the effects of the air flow rate though the fabric on the aerodynamics and the stall characteristics of the elliptic cylinder.

Therefore, in this study, a wind tunnel test was conducted using an elliptic cylinder clothed with ski jumping suit fabrics of differing air permeabilities in order to clarify the relationship between the air flow rate and aerodynamic characteristics of the suit. We investigated how the air permeabilities of the fabrics affected the flow around the fabric surfaces by measuring fluid force and visualizing the experiments with smoke wires. The purpose of this study was to clarify the aerodynamic phenomena caused by the air permeability of fabric. In future work, we will investigate the effect of fabric air permeability on actual flight distance by using a full-scale ski jumper model.

#### 2. Experimental Apparatus and Methods

Figure 1 shows a ski jumping suit whose fabric is composed of three layers: outer layer, inside layer, and lining layer. The air permeability of the ski jumping suit can be adjusted by changing the area and the number of the holes in the middle layer of fabric. This method was used for adjusting the air permeability of the fabric. This adjustment has no effect on the fabric surface. Four types of fabrics with different air permeabilities (Case-0, Case-1, Case-2, and Case-3) were used for the wind tunnel experiments. Case-1 represented the original fabric of the ski jumping suit without any adjustments in the air permeability. For Case-0, the lining fabric was completely covered with a smooth, clear tape with zero porosity and thus, the air permeability was zero. The area of the holes was increased for Case-2. Furthermore, for Case-3, new holes were added, and the number of holes was increased with respect to Case-2. The measurements of the air permeabilities of the fabrics were carried out by the method used by Maeta et al. [4]. Details of this measurement method have already been reported on and are omitted here. Table 1 shows the air permeability of each type of fabric.

Figure 2 shows the schematic of the fabric-clothed elliptic cylinder with a height of 100 mm that was used in this study. The major and minor axes of the elliptic cylinder were c = 75 mm and b = 45 mm, respectively. The schematic diagram of the wind tunnel experimental setup and force measurement system is shown in Figure 3. The wind tunnel of the Eiffel-type was open and had no air recirculation. The center of the elliptic cylinder was chosen as the origin of the x, y, and z coordinates. A three-component force balance (LMC-3501, NISSHO-ELECTRIC-WORKS) was used to measure the aerodynamic forces acting on the fabric-clothed elliptic cylinder.



Figure 1. Ski jumping suit fabric.



Figure 2. Schematic of elliptic cylinder.

The freestream velocity (*U*) was set at 20 m/s, which was chosen based on the take-off speed for large-hill ski jumping [5]. The Reynolds number of the elliptic cylinder, based on a chord length of *c* = 70 mm, was  $1.0 \times 10^5$  at *U* = 20 m/s. Figure 4 shows the definition of the angle of attack ( $\alpha$ ) of the elliptic cylinder. For the experiments, the angle of attack of the elliptic cylinder was defined as the angle between the freestream direction and the major axis of the elliptic cylinder. If  $\alpha = 0^\circ$ , this indicates that the major axis of the elliptic cylinder is parallel to the freestream direction.

The schematic diagram of the smoke flow visualization experiment, which was performed using the smoke-wire method, is shown in Figure 5. The smoke-wire was placed at a short distance from the leading edge and in the vicinity of the surface of the fabric-clothed elliptic cylinder in order to investigate the surface flow behavior.



Figure 3. Schematic diagram of test section and force balance system.



Figure 4. The definition of an angle of attack of the elliptic cylinder.



Figure 5. The flow around the elliptic cylinder, visualized using the smoke-wire method.

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L/m²/s	0.0	43.4	58.2	65.8

#### 3. Results and Discussion

#### 3.1. Aerodynamic Performances of Fabric-Clothed Elliptic Cylinder

The lift coefficients versus the angle of attack are shown in Figure 6. It was found that the lift coefficient increased with an increase in the angle of attack for all cases before stall occured. The stall was delayed by the fabrics with higher air permeabilities (Case-2 and Case-3). Case-3 had the highest lift at the high angle of attack. The maximum lift coefficient was also higher in Case-3 than in other cases. The drag coefficients versus the angle of attack are shown in Figure 7. It was found that the drag coefficient decreased with an increase in the air permeability of the fabric. The drag coefficients obtained for Case-3 were the lowest value among all cases. The polar curve of the elliptic cylinder clothed with ski jumping suit fabric is shown in Figure 8. The lift-to-drag ratio for Case-3 was improved at higher angles of attack in contrast to the original case. Therefore, it is deduced that flight distance can be extended by wearing a ski jumping suit made of a fabric with higher air permeability, because the ski jumpers fly in a stall condition after taking off into the air from the Kante (take-off point) [6].



**Figure 6.** Lift coefficients at  $Re = 1.0 \times 10^5 = 1.0$ .



**Figure 7.** Drag coefficients at  $Re = 1.0 \times 10^5$ .



**Figure 8.** The polar curve of the elliptic cylinder clothed with ski jumping suit fabric at  $Re = 1.0 \times 10^5$ .

#### 3.2. Flow Visualization around the Fabric-Clothed Elliptic Cylinder

Figure 9 shows the flow around the elliptic cylinder, visualized using the smoke-wire method. In Case-3, the smoke traces along the upper surface appeared weaker than those of Case-0, as shown by the red circles in Figure 9a,b. The flow appeared to diminish near the suction region of the upper surface for Case-3, as marked by the red circle in Figure 9b. The strength of the surface flow was evaluated using the light reflection from the smoke flow and the brightness of the smoke reflection was measured by the illumination ratio  $I (=I_w/I_e)$ , where  $I_w$  and  $I_e$  were the illuminations at the positions of the smoke wire and the upper surface, respectively, as shown by the red circle in Figure 9. Table 2 shows the comparison of illuminance ratios for Case-0 and Case-3. The illuminance ratio for Case-3 was lower than for Case-0.

Figure 10 shows the flow around the upper surface of the fabric-clothed elliptic cylinder, visualized at  $\alpha = 14^{\circ}$ . The surface flow for Case-3 could be observed near the trailing edge of the elliptic cylinder in contrast to that for Case-0. For the fabrics with high air permeabilities, the smoke flow permeated the surface of the elliptic cylinder through the fabric and then flowed out into the separation region through the fabric again, which suppressed stall. Therefore, the stall characteristics of the fabric-clothed elliptic cylinder were affected by the air permeability of the fabric. Figure 11 shows the flow around the lower surface of the fabric-clothed elliptic cylinder was no difference in smoke flow behavior around the lower surface for Case-0 and Case-3. Therefore, the air permeability of the fabric affected the flow on the upper side of the elliptic cylinder and caused a difference in the flow separation position.

Estaria	Case-0			Case-3		
radric	$I_w$	Ie	Ι	$I_w$	Ie	Ι
Illuminance	254	67	0.26	254	32	0.13

**Table 2.** Illuminance ratio of smoke flow ( $\alpha = 0^{\circ}$ ).



**Figure 9.** Smoke-wire flow visualization around test model ( $\alpha = 0^{\circ}$ ,  $Re = 1.0 \times 10^{5}$ ).



(a) Case-0

(b) Case-3

**Figure 10.** Smoke-wire flow visualization around upper surface of test model ( $\alpha = 14^\circ$ ,  $Re = 1.0 \times 10^5$ ).



(a) Case-0



**Figure 11.** Smoke-wire flow visualization around lower surface of test model ( $\alpha = 14^{\circ}$ ,  $Re = 1.0 \times 10^{5}$ ).

## 4. Conclusions

In the present study, wind tunnel experiments were carried out to investigate the aerodynamic performances of an elliptic cylinder clothed with fabrics of differing air permeabilities. The aerodynamic forces were measured using a three-component force balance and the velocity profiles around the fabric-clothed elliptic cylinder were also evaluated. The key findings are summarized as follows:

- 1. The stall angle increased with increasing air permeability.
- 2. The drag coefficient decreased with increasing air permeability.
- 3. For the fabrics with high air permeabilities, the smoke flow permeated the surface of the elliptic cylinder through the fabric and then flowed out into the separation region through the fabric again, and therefore the stall characteristics were affected by the air permeabilities of the fabrics.

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