THE EFFECTS OF UPPER LIMBS POSITION ON THE AERODYNAMICS IN SKI JUMPING FLIGHT

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In ski jumping, the jumpers are moving with high speed (about 90~100 km/h) in flight phase, so that the fluid dynamics play an important role in their performance. We focused on the effects of the position of the upper limbs of a ski jumper on the fluid dynamics in flight position. The purpose of this study was to contribute to the improvement of flight style from a fluid dynamics point of view. We measured the aerodynamic force (drag and lift) of the flight position by a ski jumper model (H: 1.50 m) to investigate the effect of the hand and arm position on the aerodynamics in ski jumping. These experiments were done in the wind tunnel of Japan Institute of Sports Sciences. The results showed that the aerodynamic forces could be changed by the body posture such as the angles of arm and hand.

KEY WORDS: hands, shoulder abduction, lift, drag.

INTRODUCTION: The flight phase of the ski jump has been thought important for achieving the good performance (distance). Provided the ski jumper described a flight curve within a perpendicular plane, the aerodynamic forces (lift and drag) and pitching moment are crucial factors on deciding the flight path. Because these aerodynamic forces and moment depend on the flight position of the jumper, it is important for a jumper to control his/her flight posture properly in aerodynamic point of view. Consequently, a number of studies have been conducted to clarify the favorable flight style in ski jumping by using the wind tunnel experiment (Jin et al., 1995; Schmölzer and Müller, 2002; Straumann, 1927; Ward-Smith and Clements, 1982; Watanabe and Watanabe, 1993).

On the other hand, the size and the materials in fabric of jump suits have been limited as smaller and standardized respectively for reducing the aerodynamic forces. Consequently, it has been more difficult for jumpers to use the aerodynamic forces for the purpose of gaining a long flight distance.

The purpose of this study was to identify the effect of arm and hand position on the aerodynamics in flight phase in ski jumping.

METHODS: The experiments were performed on a closed single return wind tunnel at Japan Institute of Sports Sciences (JISS). The wind tunnel has a rectangular outlet of 2.5 m width and 3 m height with open test section. A full-scale model (1.50 m in height) of a female ski jumper was used in the experiment (Fig. 1). Major anthropometric characteristics of this model were based on the elite Japanese ski jumper. The model had been equipped boots, jumping suit, gloves, helmet, and goggles and mounted in the wind tunnel by struts. The suit was in accordance with regulations (2014) of International ski federation (FIS). The skis were not equipped for avoiding the interference effects between the body and skis.

The lift L and drag D were measured with six-component load cell type struts which were suspended in test section. The data were acquired to personal computer by using 24 bit A/D converter board. The sampling frequency was 1000Hz. The wind tunnel experiments were performed at wind velocity of 25 m/s which is a typical take-off speed in the case of large hill ski jumping. Measurements of L, D were performed with following positions of the model, upper limb angle φ: 172°, hip bending angle σ: 10° and attack angle of trunk αt at 5° intervals from 10 to 60° (Fig. 2). To clarify the effect of arm and hand position, the shoulder abduction angle A and the hand rotation angle B were varied as A: 10, 20 and 30° and B:-90, 0 and 90°illustrated in figure 3.

Figure 1 A full-scale model of a female ski jumper in the wind tunnel.

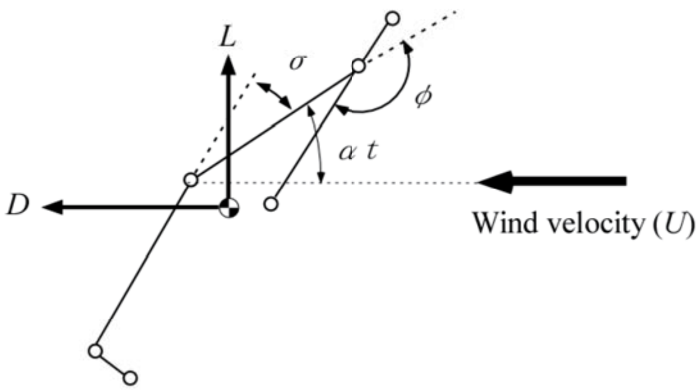

Figure 2 Aerodynamic parameters (lift (L) and drag (D), and flight positions (αt, σ and ϕ) of the ski jumper model in the wind tunnel test.

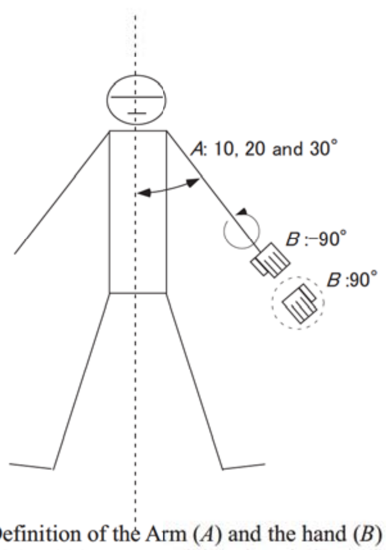

Figure 3 Definition of the Arm (A) and the hand (B) positions of the ski jumper model in the wind tunnel test.

Lift area S_L and drag area S_D were calculated from the measured forces (L and D), in the conventional manner as following equations ((Jin et al., 1995; Meile et al., 2006; Seo et al., 2004; Tani and Iuchi, 1971).

$$S_L = \frac{L}{1/2\rho U^2} \qquad (1)$$

$$S_D = \frac{D}{1/2\rho U^2} \qquad (2)$$

Where ρ and U mean the air density and the wind velocity respectively.

RESULTS AND DISCUSSION: Figure 4 shows the polar curves of S_D and S_L, with increasing the attack angle of trunk *αt*. The shoulder abduction angle (*A*) is depicted in three conditions of rotation of the hands (*B*). In the range from 10 to 40 degrees of *αt*, the smaller *A* was, the larger lift to drag ratio (*L/D*) was. These results confirm the precedent study (Meile et al., 2006) using a scaled model with skis. Present results show that the shoulder abduction angle should be smaller to get larger *L/D* in flight position in ski jumping.

Figure 5 also shows the polar curves of S_D and S_L. The hand rotation angle (*B*) is depicted in three conditions of shoulder abduction (A). In a condition of *A* was 10 and 20 degrees, C_L of the *B* = 90°were larger than those of *B* = 0° and *B* = -90°respectively, while the difference in the aerodynamic force was small in the condition of *A* was set at 30 degrees. These results show that the palm of the hand in front position should be more effective to gain the lift force in flight position in ski jumping. In addition, this effect seems much larger in relatively large angle of attack, so that the jumpers should pay much attention to the orientation of the palms in the latter part of the flight phase.

On the other hand, interference of the skis on the aerodynamics in the upper limbs was neglected in this study. An aerodynamic research in consideration of the skis will be necessary for understanding more practical knowledge of aerodynamics in ski jumping.

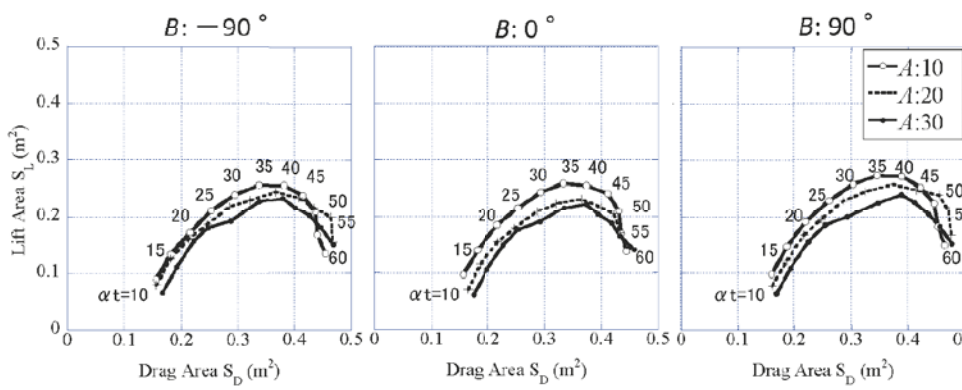

Figure 4 The effects of shoulder abduction (*A*) on the lift and drag area in each orientations of the hands (*B*) with attack angle of trunk (*αt*) .

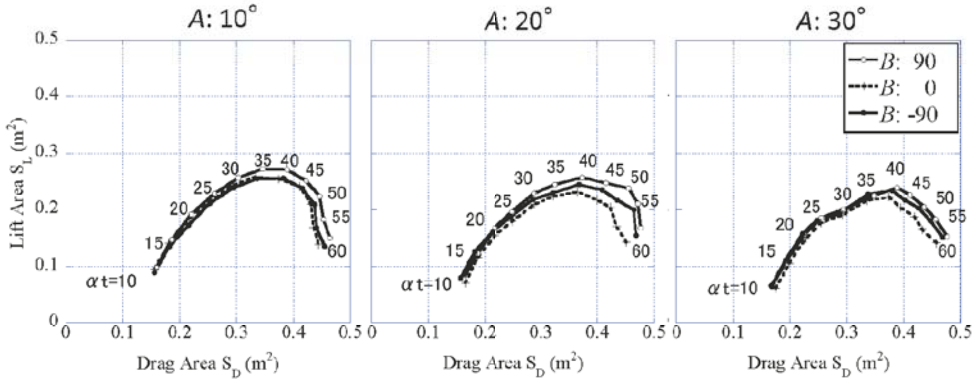

Figure 5 The effects orientation of hands (*B:* direction of palms) on the lift and drag area in each shoulder abduction condition (*A*) with attack angle of trunk (*αt*) .

CONCLUSION: In this study, wind tunnel experiments were conducted by using a full-scale model to clarify the effects of the upper limbs positions in ski jumping flight.

The results show that the shoulder abduction angle should be smaller to get larger L/D and lift force in flight position. The results also show that the palm of the hand in front position should be more effective to gain the lift force in flight position in ski jumping.

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