RELATION BETWEEN AERODYNAMIC FORCE AND FLIGHT POSTURE IN THE FLIGHT PHASE TRAINING OF SKI JUMPING USING WIND TUNNEL

Keita Akashi[1] Kaoru Yamanobe[1] Keita Shirasaki[1] Yusuke Ishige[1]
Japan Institute of Sports Sciences, Department of Sports Science, Tokyo, Japan[1]

The wind environment imitating the flight phase of ski jumping is duplicated in the wind tunnel laboratory and ski jumpers (20.7±7.1yrs) trained there for flight phase. The purpose of this study was to get the suggestion about the flight posture to extend a flight distance to analyze aerodynamic force and flight posture at the training. As the result, the jumper having high L/D was small forward leading angle, attack angle of attack, attack angle of lower limb and bending angle of shoulder ($p < .01$-05). the jumper having large SR was large attack angle of ski and small forward leading angle ($p < .01$).

KEY WORDS: aerodynamics, drag area, lift area

INTRODUCTION: It is one of the deciding factor of ski jumping performance that the function of aerodynamic force (drag force and lift force) in the flight phase. The magnitude of aerodynamic force acting on flying jumper decides by jumper's flight posture. Result on this, it is necessary that jumper control own flight posture in order to obtain the optimal aerodynamic force because jumper maximizes the flight distance. However, jumper can practice jumps only about 10 times per a day in the jumping hill, therefore improving the flight posture in the practice jump is difficult. In Japan Institute of Sport Sciences (JISS), the wind environment imitating the flight phase of ski jumping is duplicated in the wind tunnel laboratory. This makes it possible that jumper trains the flight phase while monitoring the aerodynamic force and the jumper's own flight posture.

Then, the purpose of this study was to get the suggestion about the flight posture to extend a flight distance by analyzing the flight posture of the jumpers who have characteristic in the aerodynamic force while the training of the flight phase in the wind tunnel.

METHODS:

1. Subjects: Sixteen men's ski jumpers (20.7 ± 7.1yrs)participated in this study. Their performance level is from Olympic medalist to the participant of national high school championship.
2. Setting up the training environment: The jumpers took a flight posture to the rectangular outlet (W:2.5m × H:3m) in the state being hung by the two wires (ϕ6mm) in the wind tunnel laboratory. While the jumpers trained, they could choose wind velocity from 25m/s to 33m/s. An monitor was laid in the ground plate to check the aerodynamic force and their own flight posture in real time. It was about 3~10 minutes per a training.

3. Calculating aerodynamic force: The aerodynamic force (drag force and lift force) working the jumper was calculated from the values measured using load cells and the clinometers installed in the upper end of two wires (W・A and W・B) hanging the jumper. The geometrical condition which becomes a basis of aerodynamic forces calculation was shown in the Figure 1. Equations of the drag force and the lift force was as follows.

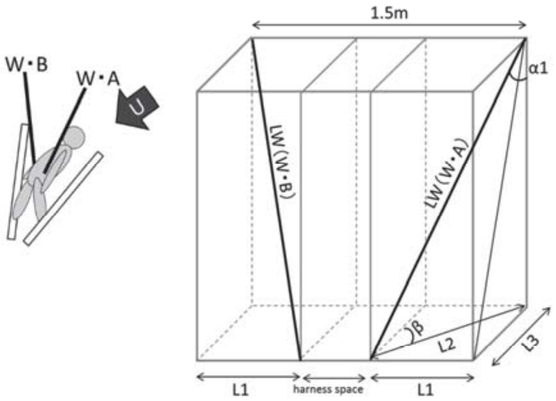

Figure 1 The geometrical condition which becomes a basis of aerodynamic force calculation

＜Constants and variables＞

L_W: wire length [m] (1.6m)
α1: Angle of inclination [deg] (W・A)
α2: Angle of inclination [deg] (W・B)
T1: Tension to work the W・A [N]
T2: Tension to work the W・B [N]
M: Body mass [kg]
g: Gravity acceleration [m/s^2]

＜Calculation＞

L1=(1500 – harness space)/2
$L2=L_W \times \sin(\alpha)$
※Calculating in the wire individually.
β=asin(L1/L2)
D (drag force)=T1×sin(α1)・cos(β1)+T2×sin(α2)・cos(β2)
L (lift force)={ T1×cos(α1) +T2×cos(α2)} – Mg

4. Analysis items: The aerodynamic force was sampled for 10 sec (1000Hz) when the measurer judged that the jumper's posture is stable while the jumper trained at the wind velocity of 25m/s. Drag force area (S_D), lift force area (S_L), resultant force area (S_R), and L and D ratio (L/D) which were the analysis items were calculated as follows from D and L.

$$S_D[m^2]=\frac{D}{\frac{1}{2}\rho U^2} \qquad S_L[m^2]=\frac{L}{\frac{1}{2}\rho U^2} \qquad S_R[m^2]=\sqrt{{S_D}^2+{S_L}^2} \qquad L/D=S_L/S_D$$

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

The images of flight posture that were filmed by two digital video cameras placed in jumper's right side and back side were extracted for 3 sec, and the following variables about the flight posture were calculated from the images using 2D-DLT method (Figure.2).

λ: ski opening angle, α:attack angle of ski, θ:forward leading angle, σ:hip angle,
ε:attack angle of attack, γ:attack angle of lower limb, φ:bending angle of shoulder
(Bending position is negative)

5. Statistical processing: The subjects were divided into two groups by the two patterns. Average values of variables in each group were compared by independent t-test (level of significance of 5%). One of the divisional patterns was six jumpers of higher L/D (H-L/D) and six jumpers of lower L/D (L-L/D), another was six jumpers of higher S_R (H- S_R) and six

jumpers of lower S_R (L- S_R).

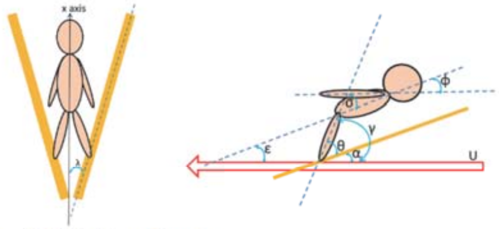

Figure 2 Definition of angles in the flying posture

RESULTS and DISCUSSION:

1. Comparison of H-L/D and L-L/D: It is recognized that jumpers having high competitive level are higher L/D in the flight phase (Murakami et al., 2014). So, the flight posture having high L/D was examined by comparing H-L/D and L-L/D (Figure 3). H-L/D had significantly higher L/D and S_L than L-L/D ($p < .01$-05). In terms of flight posture, H-L/D had significantly lower θ, ε, γ and φ (about 180deg) than L-L/D ($p < .01$-05). So, H-L/D brought skis close to their body, inclined their body forward and brought their arms just beside their trunk. It agrees the previous studies that L/D is high when θ is small (Müller, 2005). Then, it is guessed that the bigger attack angle is, the higher S_D and S_L are to some degree, however, when attack angle comes near the stall angle, L/D decreases owing to deterioration of the increasing rate of L. It is considered that jumper also can get high L/D in the actual ski jump to learn the flight posture like H-L/D in the wind tunnel. Because the flight posture having high L/D lacks stability (Mizusaki, 2004), it is meaningful to learn the posture like H-L/D in the safe training in the wind tunnel.

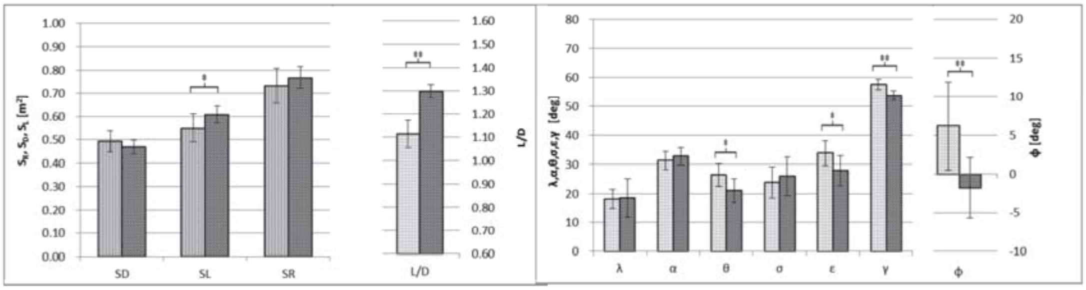

Figure 3 Comparison of variables of aerodynamics and flying posture between L-L/D and H-L/D.

＊ : significant difference at p<.05, ＊＊ : significant difference at p<.01

▨ L-L/D, ▩ H-L/D

2. Comparison of H-S_R and L-S_R: In the later flight phase, D also work to direction of lifting up jumper because direction of jumper's flying velocity vector becomes close to direction of gravity. Therefore, it is important to increase not only L but also D in the latter flight phase (Schmölzer and Muller, 2005). So, the flight posture having high S_R was examined by comparing H-S_R and L-S_R (Figure 4). H-S_R had significantly higher S_R, S_D, S_L than L-S_R ($p < .01$). L/D of both groups were more than 1. In terms of flight posture, H-S_R had significantly higher α and significantly lower θ than L-$L/_D$ ($p < .01$) in spite of having no significant difference in ε and γ. So, H-S_R raised the skis up highly and brought skis close

to their body although both groups were similar jumper's own posture. It is reported that the larger α is, the larger S_D is, and S_L is the largest when α is about 40deg (Murakami et al., 2014). It is considered that H-S_R made S_D and S_L as large as possible by being large α near the stall angle. Because α becomes about 40deg in the actual latter flight phase (Schmölzer and Muller, 2005), it is thought jumper empirically selects rational α in the latter flight phase to increase resultant aerodynamic force.

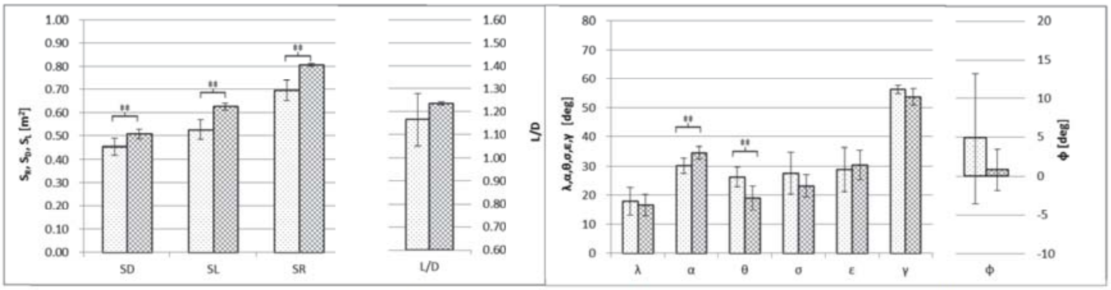

Figure 4 Comparison of variables of aerodynamics and flying posture between L-S_R and H-S_R.

＊ : significant difference at p<.05, ＊＊ : significant difference at p<.01

▒ L-S_R, ▩ H-S_R

CONCLUSION: Result of this study, it was suggested that the attention to the attack angle of trunk and lower limb and the positional relation of trunk and arms improve L/D and to the attack angle of ski improve S_R. Size of L/D is important because horizontal component of jumper's flying velocity vector is large in the early flight phase and size of S_R is important because vertical component of jumper's flying velocity vector is large in the latter flight phase. Because of these, it is thought that main point of improvement in the early flight phase is control of jumper's own body and one in the latter flight phase is control of skis. By considering these, jumper can improve the flight posture efficiency in the wind tunnel.

However, the training in the wind tunnel has several different points from the actual ski jump, for example, generation of the pitching moment by the take-off movement and change of the direction of L and D vectors by the change of the direction of jumper's flying velocity vector. It is thought that jumper can train mote effectively to reveal the detailed difference between the training in the wind tunnel and actual ski jump.

REFFERENCES:

Mizusaki, K. (2004). Biomechanical study on the postural control of ski-jumping – Focused on the second half of the flight phase – [in Japanese]. *Bulletin of the Graduate School of Education, Hiroshima University*, 53, 343-351.

Müller, W. (2005). The physics of ski jumping. *Proceedings of European School of High-Energy Physics*. Geneva: CERN, 269-278.

Murakami, M., Iwase, M., Seo, K., Ohgi, Y., & Koyanagi, R. (2014). High-speed video image analysis of ski jumping flight posture. *Sports Engineering*, 17(4), 217-225.

Schmölzer B. & Müller W. (2005). Individual flight styles in ski jumping: results obtained during Olympic Games competitions. *Journal of Biomechanics*, 38(5), 1055-1065.