AERODYNAMIC STUDY FOR THE GROUND EFFECT OF SKI JUMPING

Kazuya Seo[1], Isao Watanabe[2], Maki Igarashi[1], Shingo Kimura[1] and Masahide Murakami[3]
[1] Yamagata University, Yamagata, Yamagata, Japan
[2] University of Tokyo, Meguro, Tokyo, Japan
[3] University of Tsukuba, Tsukuba, Ibaraki, Japan

We investigated the aerodynamic forces just before taking telemark of the landing phase. The full size model was employed to measure the lift area, the drag area and the moment volume, which was mounted in a 3-meter low speed wind tunnel. The ground plate was set in the test section of the wind tunnel. The height between the ground plate and the toe of the model was from 0.4 m to 1.0 m. In the case of the V style flight, the lift area with the ground plate is always larger than that without the ground plate, though the drag area with the ground plate is comparable to that without the ground plate. The ground effect of V style flight contributes to making the larger lift in the latter half of the flight. In the case of the parallel style, the lift and the drag areas with the ground plate are comparable to that without the plate.

KEY WORDS: ski jumping, ground effect, wind tunnel experiment, lift, drag, moment

INTRODUCTION: The ground effect of ski jumping is one of the key factors to win. The importance of the ground effect of ski jumping has been recognized among jumpers and their coaches. In 1982, the ground effect was investigated using rolling ground and a scaled model (0.28 m; Ward-Smith & Clements, 1982). However, wind tunnel experiments to establish the ground effect are necessary for two reasons. One is because there is no aerodynamic data of the ground effect for the V style flight. Every jumper did the parallel style flight before 1988. The other is because the Reynolds number of the experiment by Ward-Smith & Clements was one order smaller than the practical one. In our study, we acquired the aerodynamic data of the ground effect for the V style in the range of the practical Reynolds number. The question is whether the lift near the ground is larger or not compared to that during the free flight.

METHODS: A full size model of a ski jumper was mounted in the 3-meter low-speed wind tunnel at the Research Center for Advanced Science and Technology, University of Tokyo as shown in Figure1. The ground plate was set at 0.66 m above the lowest point of the bellmouth. Strictly speaking, a rolling ground should be used in order to simulate the flight near the ground. However, the boundary layer thickness on the ground plate is less than 10 mm in this case. This allows us to do the ground effect experiment with the fixed ground plate. The height of the ground plate was not varied in this series of the experiment. The lift, the drag and the pitching moment were measured with the external six-components platform balances located above the test section. Lift is given as the sum of L1 and L2. Drag is directly given from the tension of the drag wire. The pitching moment can be calculated from the total sum of the lift and drag multiplied by the perpendicular distances from the center of gravity to these forces. Nose-up

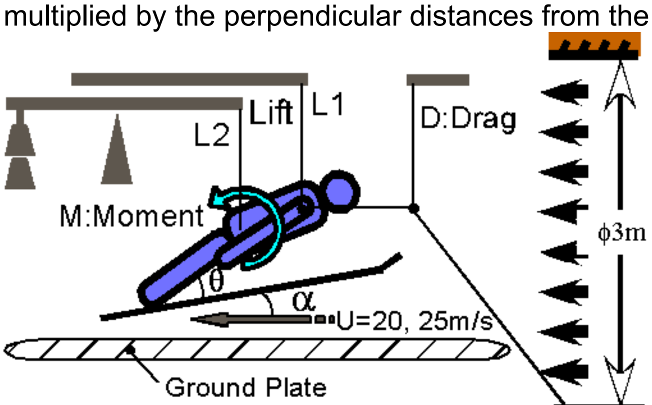

Fig.1 Experimental set-up.

rotation is determined as positive. These three were converted into the lift area (SL), the drag area (SD) and the moment volume (QM) in the following forms.

$$SD = \frac{D}{1/2\,\rho U^2} \qquad SL = \frac{L}{1/2\,\rho U^2} \qquad QM = \frac{M}{1/2\,\rho U^2} \tag{1}$$

ρ is the density of the fluid, U is wind speed. The angle of attack, α, is the angle between the ski and the flight direction. The forward leaning angle, θ, is the body-ski angle. There was an experimental limitation of the sum of α and θ. As this increases, the ski tails get closer to the ground plate and make contact. The experimental range of the sum of α and θ with the ground plate was from 0 to 40°. The wind speed, U, was 20 or 25 $m \cdot s^{-1}$. The ski-opening angle (ski-ski angle), λ, was set at 0, 10 and 26°.

RESULTS AND DISCUSSION: The aerodynamic data with the ground plate is compared to those with no ground plate as a function of the angle of attack, α, in Figure 2. The aerodynamic data with the ground plate are shown by a solid line, and those with no ground plate are shown by a dotted line. Both the ski-ski angle, □, and the forward leaning angle, θ, are 10°. SL with the ground plate is always slightly larger than that with no ground plate, though SD is almost the same. QM with the ground plate is comparable to that with no ground plate below □ = 20°. QM with the ground plate becomes negative above 25°, though QM with no ground plate is still positive until 37°. It has been shown from video analysis that the practical values of □ and □ are about 40° and 10° respectively. Around these values, we could not acquire aerodynamic data because of the limitation of the sum of □ and □. However, it seems likely to be negative around these □ and □ (that is, nose-down rotation). This means that the jumper could land on the landing area smoothly, which has the negative slope from the horizontal line. Figure 3 is the same plot in the case of the parallel style flight. SL and SD with the ground plate are almost comparable to those with no ground plate. It becomes clear that the ground effect of the V style flight contributes to larger lift in the latter half of the flight. If we take account of the larger SL near the ground, the flight distance is estimated at about 115 m by solving the optimization problem numerically (Seo et al., 2000). In this estimation we assume that the ski-ski angle, λ, is constant at 10° during the flight. This flight distance is 3 m longer than that without taking account of the larger SL near the ground. The difference between SL

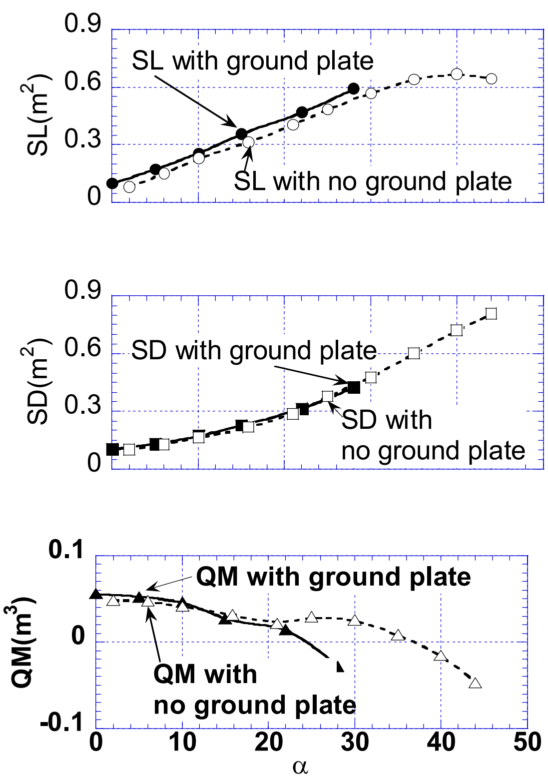

Fig.2 SL, SD, QM differences between the data with the ground plate and those with no ground plate in the case of V style flight.

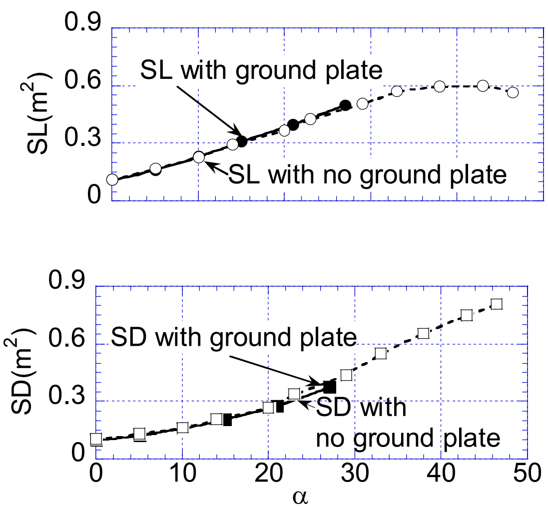

Fig.3 SL, SD differences between the data with the ground plate and that with no ground plate in the case of the parallel style flight.

with the ground plate and that with no ground plate becomes larger with the increase of the ski-ski angle, λ, as shown in Figure 4. SL difference is the subtraction of SL with no ground plate from SL with the ground plate. The forward leaning angle, □, is 10° and the angle of attack, □, is 35°. The flight distance should be longer in the case of the larger λ because of the larger lift. The practical value of □ is about 35°. As shown in the lower part of figure 2, QM changes sign from positive to negative with the increase of the angle of attack, □. Where QM has a negative slope for □ and equals zero is a stable equilibrium point for pitching oscillation. The period of the pitching oscillation is given by (Yoshida, 1998):

$$T = 2\pi\sqrt{\frac{-1}{k}} \quad , \quad \left(k = \frac{1}{2I}\rho U^2 \cdot \left.\frac{dQ_M}{d\alpha}\right|_{\alpha_0} \right) \qquad (2)$$

where I is the moment of inertia around the center of gravity of jumper-ski combination. Getting the value of *dQM/d*α from the experiment, one can estimate the period, T, as shown in Figure 5. The ski-ski angle is 10° and the forward leaning angle, □, is taken as a parameter. The wind speed is 30 $m \cdot s^{-1}$, which is the practical value just before landing. The periods with the ground plate are shown by closed marks, and those with no ground plate are shown by open marks. It is found that the existence of the ground makes the period shorter when compared with that of the free flight under the same □ condition. The period is about 2 seconds at □□= 10º.

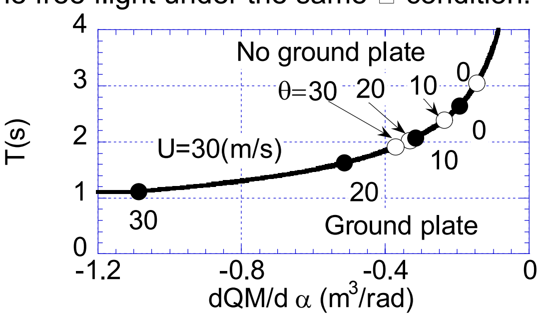

Fig.5 The period of the pitching oscillation around the stable equilibrium point.

CONCLUSION: The wind tunnel experiment with the ground plate reveals the following:

1. In the case of the V style flight, the lift area with the ground plate is always larger than that with no ground plate, though the drag area is almost same. The difference of the lift area between with the ground plate and with no the ground plate becomes large with the increase of the ski-ski angle.
2. In the case of the parallel style flight, the lift and the drag areas with the ground plate are comparable to that without the plate.
3. The existence of the ground makes the period of pitching oscillation around the stable equilibrium point shorter when compared with that of the free flight.

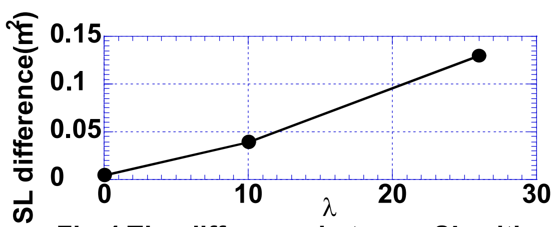

Fig.4 The difference between SL with the ground plate and SL with no ground plate.

REFERENCES:

Seo, K., Watanabe, I., Murakami, M.,
Ikeguchi, T., Miura, A. and Igarashi, M. (2000). The optimization of the forward leaning angle during ski jumping flight. Symposium on sports Engineering 2000, pp.135-139 (in Japanese).
Ward-Smith, A.J. and Clements, D. (1982). Experimental determination of the aerodynamic characteristics of ski-jumpers. *Aeronautical Journal* December 1982, pp.384-391.
Yoshida, K. (1998). Investigation of Optimal Ski Jump Flight on the basis of Aerodynamic Data. Master's thesis 1998, Institute of Engineering Mechanics, University of Tsukuba.

ACKNOWLEDGEMENTS:

This work is supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Scientific Research, 13750840, 2001.