The Optimum Angle Controls During Ski Jumping Flight

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Introduction

Ski jumpers have to control their angles such as the ski-opening angle of V-style flight or the angle of attack from time to time in order to make the longest flight distance. They have acquired their own angle control techniques based on their experiences and coaches’ advice. However, it has been recognized that to reveal the optimum angle control technique on the basis of aerodynamics is strictly necessary as well as empirical knowledge. The optimization study has been made by P. Remizov (1984). The angle of attack was chosen as a control parameter under the condition that the two skis were parallel. Every jumper did the parallel style flight before 1989. In 1989, a new flight style named V-style was developed by a Swedish ski jumper. There still remains an open question how a jumper should control the ski-opening angle of V-style flight from time to time in order to make the longest flight distance. This is thus the very objective of this study. In this study, the ski-opening angle and the angle of attack are chosen as control parameters for the maximum flight distance.

Methods

We solved the optimization problem taking account of the equations of motion on the basis of aerodynamic data. Aerodynamic forces acting on the full size model of a ski jumper were measured as the drag area, SD, lift area, SL, which were given by

\[ SD = \frac{D}{1/2\rho U^2} \quad SL = \frac{L}{1/2\rho U^2}. \quad (1) \]

Here, D and L are drag and lift, respectively. \( \rho \) is the density of the fluid, U is the speed of flight. The full size model wore the helmet, goggles, jump suits, gloves and the boots like a real jumper. It was mounted in the 3-meter low speed wind tunnel at the Research Center for Advanced Science and Technology, The University of Tokyo. The height of the model was 1.76 m, and the length of ski was 2.52 m. Aerodynamic data were acquired for a wide variety of the ski-opening angle (0 \( < \lambda < 26 \) deg.) and the angle of attack (0 \( < \alpha < 50 \) deg.). SD and SL were expressed by functions of the ski-opening angle and the angle of attack.

The definition of the characteristic parameters of the body-ski combination is given in figure 1. \( \beta \) is the flight angle between the direction of flight path and the X-axis. \( \alpha \) is the angle of attack, which is the angle between the ski and the direction of the flight path. m is the mass of body-ski combination, g is the gravitational acceleration. The ski-opening angle is denoted by \( \lambda \).

![Fig.1 Definition of characteristic parameters.](image)
The equations of motion in the directions of parallel and normal to the flight path are expressed by

\[ m \frac{dU}{dt} = mg \sin \beta - D, \quad (2) \]

\[ mU \frac{d\beta}{dt} = mg \cos \beta - L. \quad (3) \]

The flight path is given by

\[ \dot{X} = U \cos \beta, \quad \dot{Y} = U \sin \beta. \quad (4) \]

After the mathematical modeling for eqs. (2), (3) & (4), the optimal solution was numerically calculated by making use of conjugate gradient method.

**Results & Discussion**

Figures 2 & 3 are results of wind tunnel experiment. SD increases with the increase of \( \alpha \) and \( \lambda \). SL increases with the increase of \( \alpha \) until the stalling angle appears, and then SL decreases over the stalling angle. SL becomes larger for a given \( \alpha \), if \( \lambda \) increases.

Using these aerodynamic data, one can apply optimization calculation to eqs. (2), (3) & (4). Figure 4 shows the one example of the optimization. The optimized flight distance is estimated about 140 m in the case of Okurayama jumping hill in Sapporo, Japan. \( \alpha \) increases monotonously with time and reaches 36deg. at the very last time of the flight. Since \( \beta \) is about –38deg. at that time, ski points to almost
X-axis. $\lambda$ increases up to $31^{\text{deg}}$ at 2.7 s, and then $\lambda$ decreases to $25^{\text{deg}}$. These angle controls contribute making small SD in the first half of the flight and large SL in the later half as shown in figure 5.

References

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