Japanese Journal of Applied Physics
Vol. 26, No. 7, July, 1987, pp. 1185–1189

Experimental Study of the Mechanism of Skiing Turns. I. An Uphill Turn from Straight Running Downhill

Toshio Sahashi and Shoji Ichino[†]

Department of Electrical Engineering, Daido institute of Technology,
Minami-ku, Nagoya 457
[†]*Department of Physical Education, Aichi University of Education,*
Kariya, Aichi 448

(Received October 11, 1985; revised manuscript received March 30, 1987;
accepted for publication April 25, 1987)

The aim of the present paper is to show, using a small model ski sliding on a flat sand slope, that by setting a ski on its left/right edge in a straight downhill run that this will lead to a left/rightward turn. The turn is assisted by an accompanying upward flex of the tip section. The result is supported by a field experiment with a real ski on snow.

§1. Introduction

Many textbooks on skiing can be found in the market; however, scientific work so far published on the mechanism of skiing turns are very few. Kinosita[1] made a careful analysis of the mechanics of skiing turns by taking the effect of the skew angle into account. Morawski[2] has discussed skiing turns in terms of the control of the skier's body bank angle. Lieu and Mote[3] have discussed steady-state turns, and classified them into carving and skidding turns. These theories, however, have not been experimentally verified. The present experimental study with one model ski on a sand slope was made in order to clarify various basic factors that contribute to skiing turns.

§2. Experimental Methods

Three types of model skis made of vinyl chloride, $19\times2\times0.08$ cm^3, with a curved tip (but with no camber) were prepared: Type 1 with a straight side-cut, Type 2 with a convex ($R=-150$ cm) side-cut and Type 3 with a concave ($R=150$ cm) side-cut (Fig. 1). The Young's modulus of the vinyl chloride was 3.5×10^4 kg/cm^2. A short, vertical aluminum cylinder was fixed to the ski with its axis on the central point of the ski. On top of the cylinder was fitted a circular iron plate. By shifting four magnet pieces placed on the iron plate, we were able to displace the center of gravity of a ski complex (ski + cylinder + plate + magnet pieces) which weighed 36 g. The center of gravity G was located 0.57 cm above the bottom surface of the ski.

The model ski was allowed to slide down a slope of fine sand (diameters <0.05 cm) with an incline α ($\approx26°$). The sand was packed in a box 180 cm long and 80 cm wide to a depth of 1 cm.

In order to fix the edging angle throughout test runs, we employed in some of the experiments a gate-type ski holder (Fig. 2), which was furnished with two auxiliary skis with their soles flat on the sand surface. The edging angle β of the main ski (Type 1, 2 or 3) was kept at a predetermined value by fixing aluminum piece A to B. The latter, B, moved freely but only in the direction

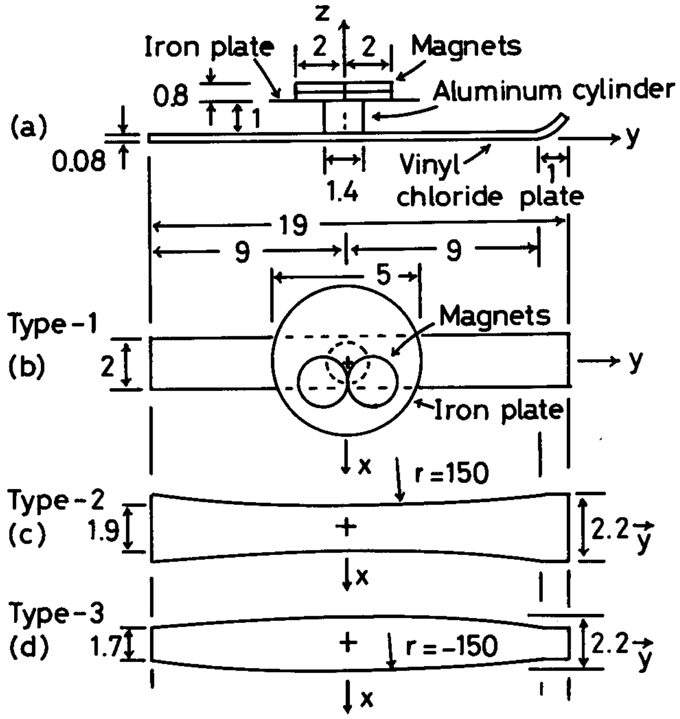

Fig. 1. Model skis of vinyl chloride and the x, y, z-coordinate system. Side views of (b), (c) and (d) are as shown in (a).

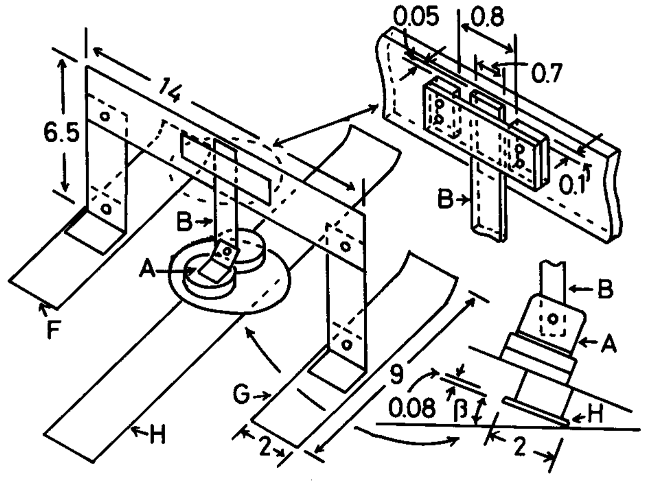

Fig. 2. Gate-type ski holder. The soles of auxiliary skis F and G are kept flat on the slope. The main ski H is edged at a fixed angle β. It can move freely in the vertical direction.

perpendicular to the sand surface. The gate-holder weighed 30 g.

In the field experiment described in Fig. 11, a 180 cm long real ski, on which a 20 kg iron lump was fixed on the boot position, was allowed to run along the snow.

A photograph of the ski was successively taken at an interval of 0.25 s in field as well as laboratory experiments.

§3. Results

The position of the center of gravity, G, is hereafter be expressed by using an orthogonal coordinate system x, y, z fixed to the ski, with its origin at the ski center point; the xy-plane lies in the bottom surface of the ski and the y-axis along the length of the ski. The coordinates of G, x, y and z in cm, are given *e.g.* by G(0.00, 0.00, 0.57) if $x=0.00$ cm, $y=0.00$ cm and $z=0.57$ cm.

3.1 *The coefficient of kinetic friction*

The coefficient of the kinetic friction μ between the vinyl chloride ski and the sand surface was determined by measuring the acceleration of the ski from a series of pictures taken at an interval of 0.25 s. For the Type 1 ski with G at (0.00, 0.00, 0.57), μ was estimated at 0.42 ± 0.02.

3.2 *Uphill turns*

When a Type 1, 2 or 3 ski was allowed to slide down along the fall line after it had been edged by fixing x at a positive value, the ski made a right uphill turn. As an example, the result for a Type 1 ski for G(0.50, 0.00, 0.57) is shown in Fig. 3((a): before starting. (b) and (c): 1 s and 2 s after the start, respectively). Tracks 1, 2 and 3 in (a) represent the results for the cases G(0.31, 0.00, 0.57),

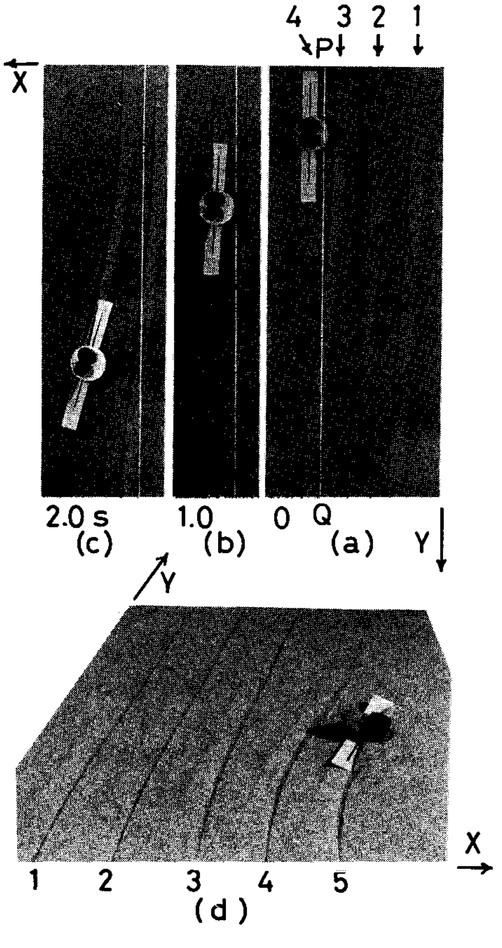

Fig. 3. (a)-(c): Uphill turn of Type 1 ski. The XY-plane lies in the sand slope. The Y-axis is along the fall line. The white line P-Q is a thread stretched along the fall line 4 cm above the slope. (d): Back view of the ski used in (a)-(c).

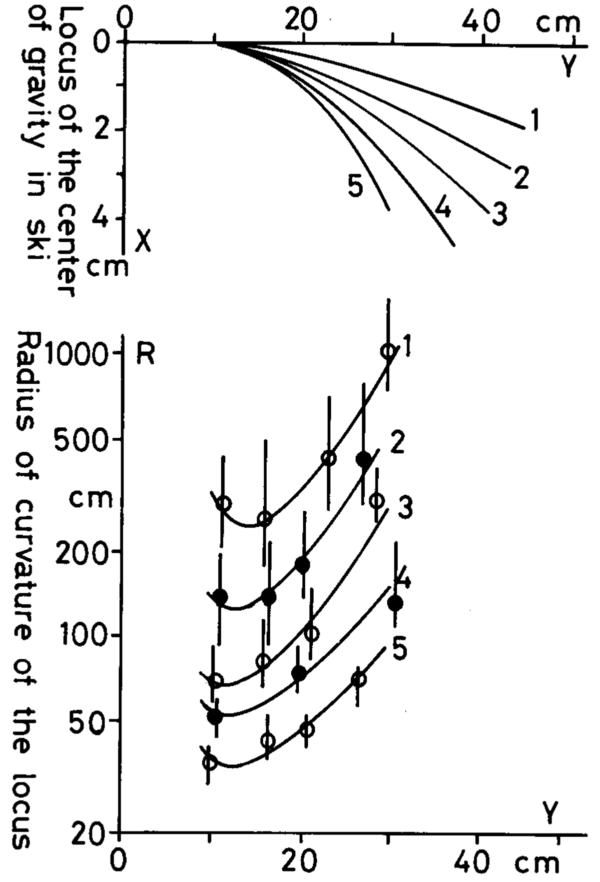

Fig. 4. Locus of the center of gravity G and radius of curvature R of the locus (Type 1). Numbers 1 to 5 correspond to those in Fig. 3(d), respectively.

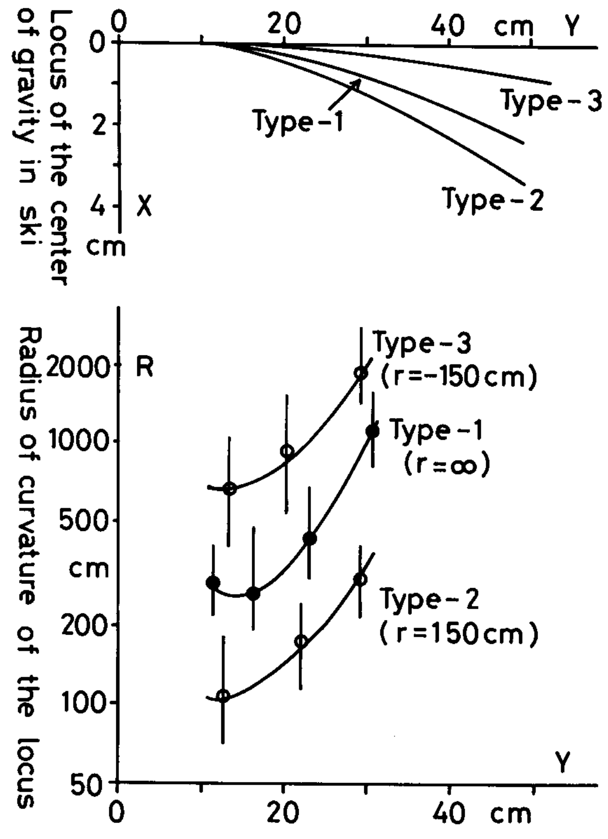

Fig. 5. Locus of the center of gravity G and radius of curvature R of the locus (Type 1, 2 and 3).

G(0.38, 0.00, 0.57) and G(0.44, 0.00, 0.57) respectively, and Track 5 in (d) for G(0.54, 0.00, 0.57). Figure 4 gives measurements of the tracks shown in Fig. 3. Figure 5 gives the results for Types 1, 2 and 3 with G(0.31, 0.00, 0.57). We observe that (1) if x is fixed at a positive/negative value, all three types of ski are edged on their right/left and they make a right/left turn; and (2) the radius of the track R decreases with an increases in $|x|$; for the same value of $|x|$, R increases in the order Type 2, Type 1, Type 3.

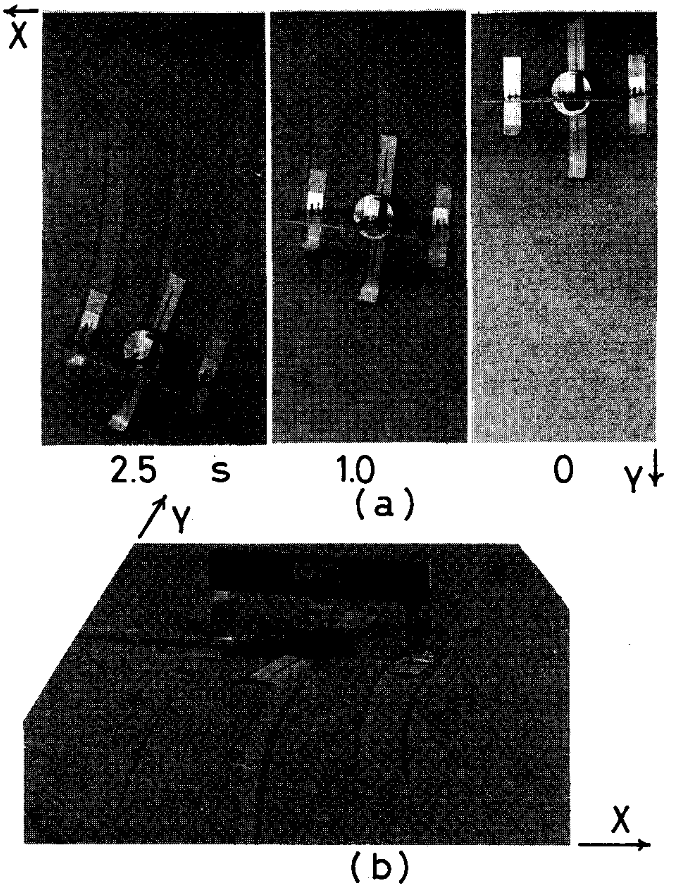

Fig. 6. Ski (Type 1) held in the gate-type holder. (a) Top view. (b) Back view.

3.3 *Uphill turns with a ski held in a gate-type holder*

Figure 6 shows an experiment for a Type 1 ski with G(−0.31, 0.00, 0.57), whose edging angle was fixed at $\beta = 10°$. When it was allowed to slide down along the fall line, it started to make an uphill turn. Figure 6(b) shows a back view of the ski. All three Types of skis made turns in one and the same direction when β was the same, not withstanding the value of x. Figure 7 gives measurements of the tracks for Types 1 and 2 for three values of β. We found that the radius R decreases with an increase in the edging angle β, regardless of the type of ski.

3.4 *Upward flexion of the forebody*

From the ski shadow projected on the sand (Type 1, G(−0.47, 0.00, 0.57) in Fig. 8), the perpendicular distance h between the ski edge and the sand surface could be estimated (Fig. 9(a)). The value of h varies along the length of the ski; it also changes as the ski slides down (Fig. 9(b)). The ski is almost flat before it starts; the forebody begins to flex upward with time.

3.5 *Uphill turn experiment with a transparent ski*

A transparent type ski made of vinyl chloride having the same dimensions as the one shown in Fig. 1(b) was prepared. The ski was edged by displacing G toward the $+x$ direction, G(0.44, 0.00, 0.57), and was allowed to slide down along the fall line (Fig. 10(a)). In Fig. 10(b) are shown changes in the contact area of the ski sole and the sand surface, which were observable by virtue of the transparency of the ski. The non-symmetry of the contact area with respect to the y-axis is due to the edging angle. The non-symmetry with respect to the x-axis in-

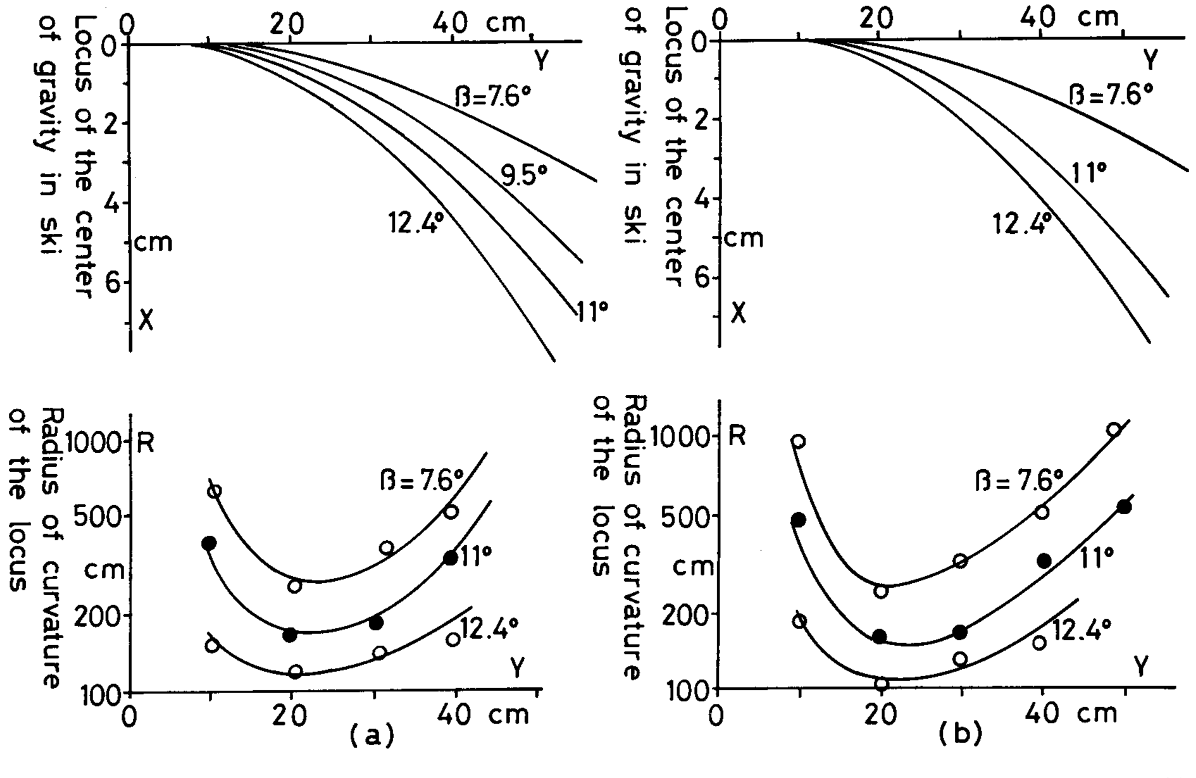

Fig. 7. Locus of the center of gravity G and radius of curvature R of the locus. (a) Ski (Type 1) held in the gate-type holder. (b) Ski (Type 2) held in the gate-type holder.

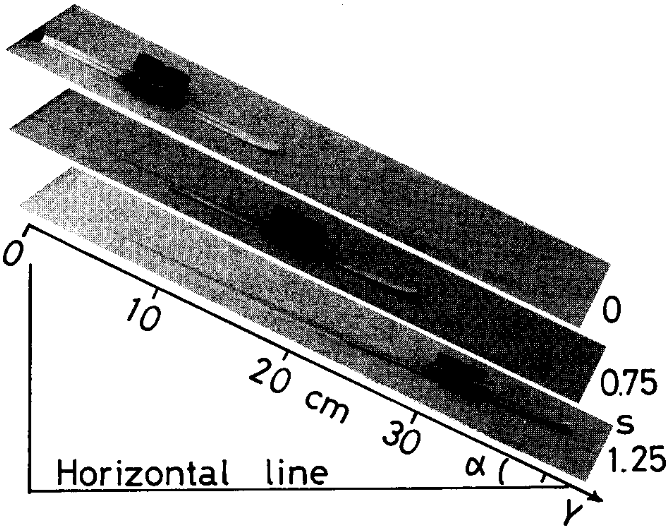

Fig. 8. Upward flexion of a sliding ski.

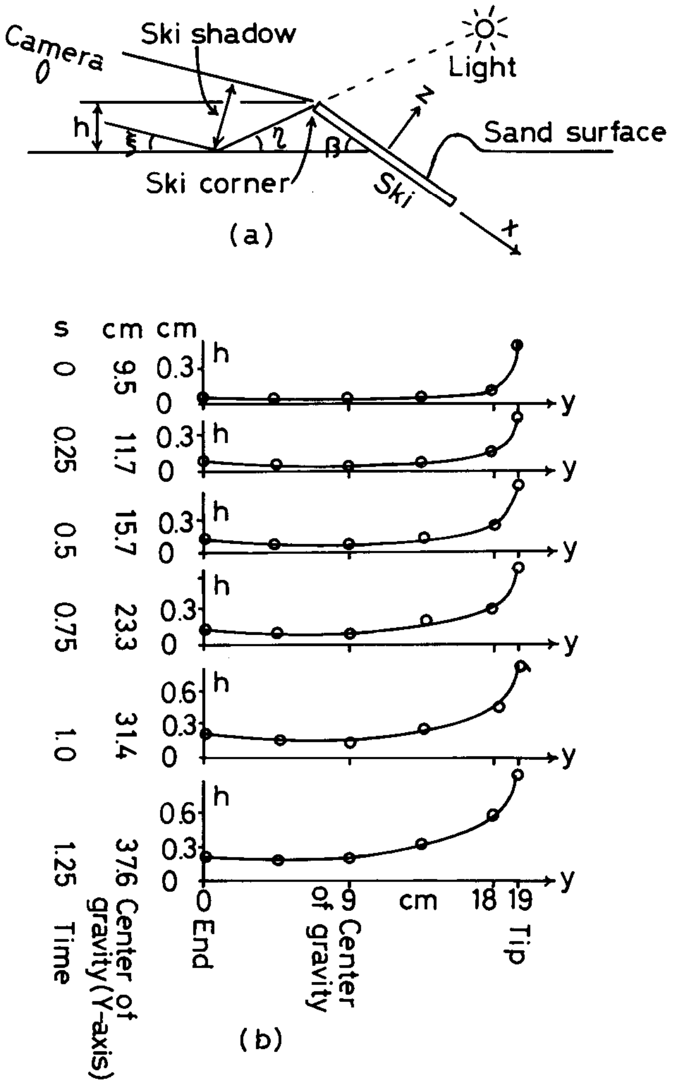

Fig. 9. (a) Measurement of the perpendicular distance h between the ski's edge and the slope.

creased as the ski slid down. We observe that the contact area is smaller for the forebody than for the afterbody. This is in accordance with the flexion of the ski shown in Fig. 9(b).

3.6 *Preliminary experiments with a real ski on the snow*

When a real ski, G(1.18, 1.1, 6.33), began a downward slide, being edged along the fall line on a snow slope with an incline $\alpha=10°$, the ski made an uphill turn (Fig. 11). The snow temperature was -6°C (packed powder). The coordinate system for G has the xy-plane lying in the bottom surface of the ski with the origin below the iron lump center. This experiment showed that the ski turned more sharply with an increase in the displacement of G in the x-direction.

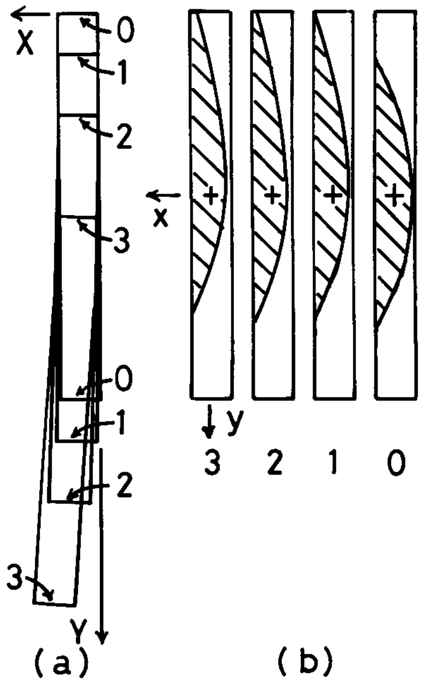

Fig. 10. Contact area between ski and sand. (a) Track. (b) Contact area (oblique lines).

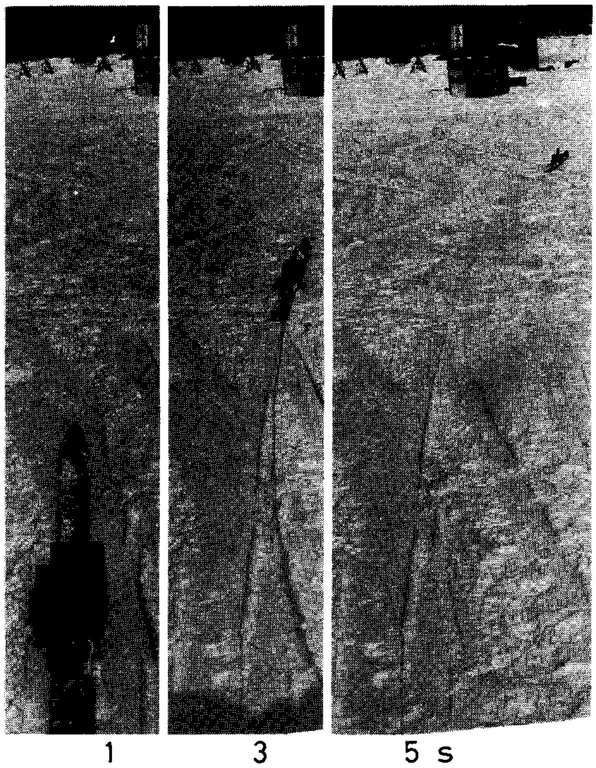

Fig. 11. Uphill turn from straight running downhill of a real ski on the snow.

§4. Discussion

4.1 *Factors inducing a turn*

(A): In those experiments that are illustrated in Figs. 3 to 5, which we will call Experiment Series A, we found that: (1) if the displacement of G from the origin, x, was fixed at a positive/negative value, the ski was edged on its right/left, and the ski made a right/left turn; (2) the radius of curvature R of the track decreased with an increase in $|x|$; and (3) the radius R increased in the order Type 2, Type 1, Type 3. Note that the edging angle β changed its magnitude as the turn proceeded.

(B): In the experiments shown in Figs. 6 and 7, which we will call Experiment Series B, we found that: (1) if the ski was edged on its right/left, it made a right/left turn; (2) R decreased with the increase in β; and (3) R was affected neither by the value of x nor by the side-cut.

(C): In Figs. 8 to 10, the forebody of the sliding ski was always found to make an upward flexion.

In Series A, three types of skis, each having a specific side-cut, were used, and x and β were changed for successive experiments. In Series B, only β was changed for successive experiments. The upward flexion of the forebody was observed in A as well as in B. It is concluded, therefore, that among the four factors taken up in this paper the edging angle β and the flexion of the forebody are the primary factors that rule the uphill turn from the straight running downhill; the side-cut and the displacement of G, x, play only secondary roles.

4.2 *Mechanism of skiing turn*

It is necessary for a skiing turn to take place in which a force normal to the running direction and parallel to the slope acts on the ski, and that this force does not pass through the projection on the slope of the center of gravity of the skier-ski system. G_s Kinosita(1) explains the skiing turns on the assumption that the normal force is given by the resistance against the side-slip, the resultant of which does not pass through G_s by virtue of the flexion of the skis. In the initial stage of our experiment, however, such a force could not be expected since the ski was running straight downhill. Morawski(2) claims that a turn or a turn initiation is made by the skier's control of his body bank angle. However, since the model ski in our experiment was not controlled by the skier, Morawski's theory is inapplicable. Piziali(4) has experimentally shown that the pressure of snow is less on the tip than on the other parts of the ski. This was probably true in our experiment as well, because the forebody of the ski was found to bend upward. Some texts(1,5,6) emphasize that a turn is initiated by the skier's jumping motion, by the rotation or counter rotation accompanied by unweighting of his body, or by the help of ski poles, etc. The present experiment has shown that an edged ski can initiate a turn without such aids.

4.3 *Sand ski and snow ski*

The coefficients of kinetic friction μ of the ski on the sand and on the snow were, in our experiment, 0.4 and 0.02, respectively. In spite of the difference in μ and in the ski length similar results have been obtained in the experiments in Figs. 3 and 11, showing that there is no essential difference in the mechanism between a turn on sand and that on snow.

Acknowledgments

The authors thank Prof. T. Okabe, Prof. T. Ishikawa and Mr. Okamoto of Daido Institute of Technology for their valuable discussions. Thanks are also due to Mr. Kamihira in Hohnoki-daira Ski Area, Gifu Prefecture, for the preliminary experiment on snow.

References

1) K. Kinosita: *Ski no Kagaku* (Science of Skiing) (Chūō Kōron Sha, Tokyo, 1973) [in Japanese].
2) J. M. Morawski: J. Biomech. **6** (1973) 267.
3) D. K. Lieu and C. D. Mote, Jr.: *Skiing Trauma and Safety: 5th. Int. Symp.* ASTM Special Tech. Public. 860 (1983) 117.
4) R. L. Piziali and C. D. Mote, Jr.: J. Dynamic Systems, Meas. & Control, Trans. ASME. **94** (1972) No. 2 (June) 133.
5) G. A. Broten and G. R. Twardokens: Jopher (1972) January 57.
6) K. Gamma: *The Handbook of Skiing* (Pelhambooks, 1981).