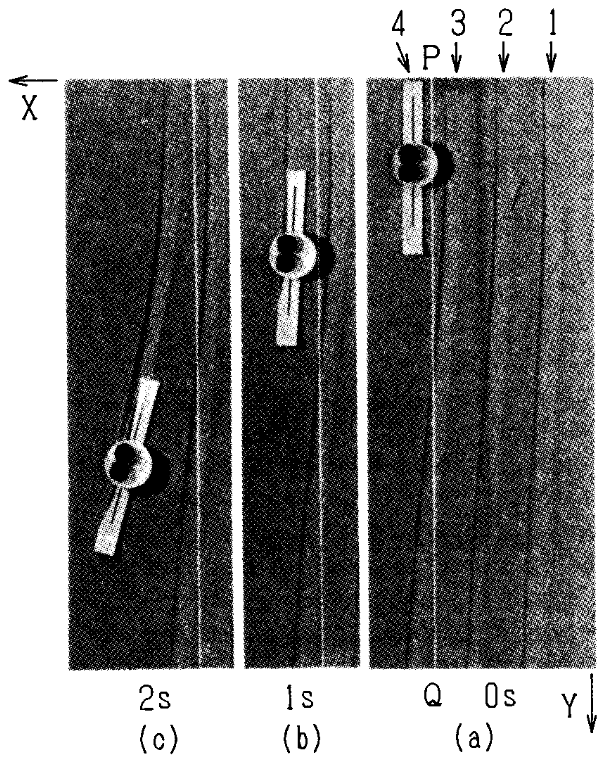

Fig.7 Uphill turn of a straight ski; (a) at a starting point, (b) one second after the start, (c) two seconds after the start.

direction (A3). Here the explanation is given using the example shown in Fig.7. The X and Y axes are identical to the X and Y axes in Fig.5. The white line PQ is a thread extended along the fall line, 4 cm above the sand plane. No.1 is the track of the ski with its center of gravity positioned at x=0.31cm, No.2 at x=0.38cm, No.3 at x=0.44cm, and No.4 at x=0.50cm. As shown in Fig.7, with increasing distance between the center of gravity and the center of the ski (the ski includes objects placed on it), the ski turns more. Since sand is composed of fine particle, as the center of gravity of the ski deviates from the center of the ski, the angle between the ski and the slope, namely, the inclination angle of the ski, increases. Therefore, in the initial stage of our experiments, we could not determine whether turns depended (a) on the change in the position of the center of gravity or (b) on the change in the inclination of the ski. We were able to distinguish between (a) and (b) only recently, with respect to the cause of ski turns.

(2) Next, the motion of the ski observed from the θ direction (B3) is explained using Fig.8. The angle α is the angle of the slope and PQ is the fall line. A skier skiing on one foot slides down the slope DGFB along the curved line from S to O to T. The sliding plane JIHC is an enlarged area around position O. The ski abcd is on the sliding plane. The sliding direction HC is a tangential line of the track of the turning descent from S to O to T. The direction of the ski usually differs from the sliding direction, as shown in this figure. The line Ce is on the slope DGFB. The line Cf is on the sliding plane inclined by angle β to the slope. The line Ch is inclined from the sliding

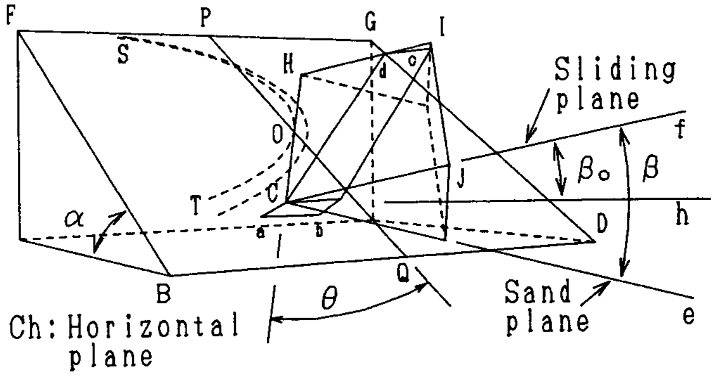

Fig.8 Model of a ski slope.

plane by angle β_0, and is on the horizontal plane. Here, β is the edging angle to the slope and β_0 is the edging angle to the horizontal plane. The angle θ is defined as shown in Fig.9(a), and can be measured from ~~the angle in~~ the photograph shown in Fig.7. The angle β can be obtained by measuring the inclination of the sliding track of the ski after the ski-sliding experiment, as shown in Fig.9(b). Namely, using a straight ruler and a triangular ruler which are in contact with the sand surface, lengths a and b are obtained to calculate angle β. The two rulers are fixed on a

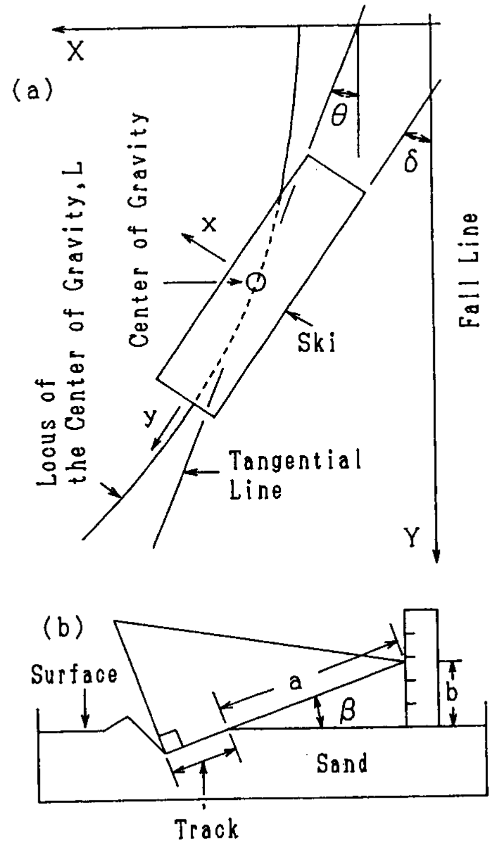

Fig.9 (a) Angles δ and θ. δ is an angle between the ski direction and the fall line. θ is an angle between the tangent line of a locus of the center of gravity of the ski and the fall line.
(b) An angle between the plane of the ski track and the sand plane (edging angle β).

*Ski Association of Japan

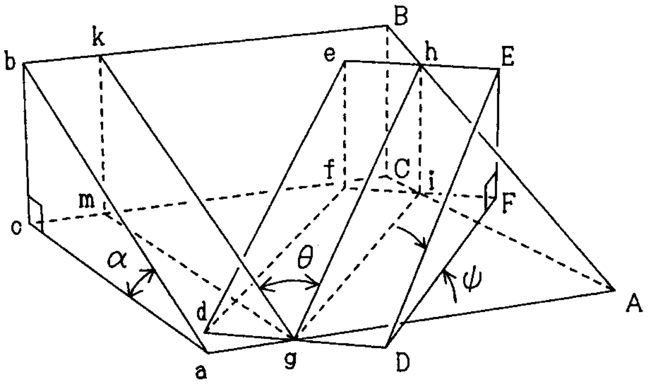

Fig.10 Illustration of a straight downhill run and traverse on a model. aACc and dDFf are on the same horizontal plane.

crossbar support placed above the sand plane. The angle β_0 can be calculated using three measured values:[8] the inclination angle of the slope, α, the tangential angle θ, and the edging angle β.

This angle β_0 is the inclination of the ski observed from the direction θ, as shown in Fig.8. We investigated the relationship between β_0 of the sand ski and the turning-descent direction (θ direction) of the ski, and found the following: when $\beta_0>0^\circ$, the ski turns right (uphill turn). When $\beta_0=0^\circ$, Cf becomes identical to Ch and the ski descends straight in the direction of HC. When $\beta_0<0^\circ$, the ski turns left (downhill turn). Namely, $\beta_0\neq0^\circ$ is the condition of turning descent, and $\beta_0=0^\circ$ is the condition of straight descent.[8] This is a significant discovery to obtain a clue for the clarification of the mechanisms of ski turns. It was obtained in October 1983, three months after the start of our ski experiments.

7. The β_0 rule

Whether a ski turn is an uphill turn or a downhill turn depends on the sign of β_0. The fact that $\beta_0=0^\circ$ is a straight descent means that a "*straight downhill run is the same as a traverse.*" Let us explain this using Fig.10. The planes aACc and dDFf are on the same horizontal plane. The fall line at the inclination angle of the slope, α, is kg. The fall line is a line of the straight downhill run. The fall line of the inclination angle of the slope, ψ, is hg. The line hg is a line of traverse with the inclination angle of α. Thus, we can see that both the straight descent and the traverse satisfy $\beta_0=0^\circ$.

β_0 is the edging angle relative to the horizontal plane. In other words, only the relationship between the direction of the ski and the direction of gravity determines the turning direction of the ski as well as the straight descent. We call this rule the β_0 rule.[9]

Next, we placed a 20-kg weight in place of a skier on an actual snow ski and performed sliding experiments on a ski slope (Fig.11).[7] The β_0 rule also holds on the snow plane. In addition, the β_0 rule was also confirmed for sliding tracks of a ski with a skier (a ski sliding with slight skiddings) on a snow plane (Fig.12).[9] Thus, regardless of the presence of a skier on a ski, and regardless of a sand or snow plane, the β_0 rule holds.[9] In the β_0 rule, the inclination of a ski is considered but the turning of a ski is not. Accordingly, the skier's will regarding turning is disregarded in the β_0 rule.

In contrast to the above, according to the theory of skiing in Section 2, "*skis turn because a skier twists his body.*" In this theory of skiing technique, the skier's will to turn the skis causes the skis to turn. Therefore, the conventional skiing technique theory contradicts the β_0 rule.

According to * ~~the textbook of the Japan Society of Ski Sciences~~ *,[4] "*ski-turning techniques include mainly of rotation, edging and loading.*" This seems to describe the skier's operation of skis; however, since the definitions of the terms rotation, edging and loading are ambiguous, it is difficult to understand the cause of parallel turns (ski descent with slight skiddings) from the textbook.

(1) The "*edging angle*" in the textbook is considered to correspond to angle β in our study. In our experiments, ski turns depend not on angle β, but on β_0. In the textbook, the relationship between the edging angle and the direction of a turn is not clearly described.

(2) If the causes of a parallel turn depend only on "*rotation,*" then, similar to Section 4, this theory contradicts the law of conservation of angular momentum.

(3) If the causes of a parallel turn include "*rotation*

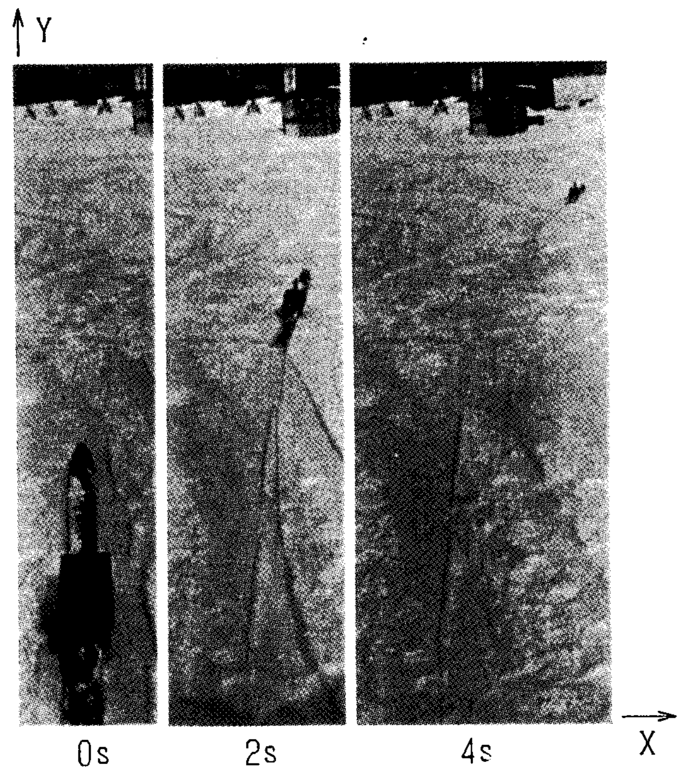

Fig.11 Demonstration of an uphill turn of an actual snow ski on a snow plane. A 20-kg-weight iron plate is placed on the ski in place of a skier.

Fig.12　Turning descent of a skier skiing on one foot on a snow plane.

and edging," then the following question arises: when a skier performs edging to the right while twisting his body to the left, in which direction do the skis turn ?
(4) Issues of loading will be discussed in the next article. To make use of the experimentally proven β_0 rule, the only method will be to exclude rotation from the causes of a turn. When a skier is performing a turning descent, "*the skier feels that he makes the skis turn,*" or "*he believes he makes the skis turn;*" we define this as "the skier's sense of making a ski turn." Let us clarify the sense of making a ski turn.

8. Sense of making a ski turn

In the winter of 1984, we repeated the experiments described in Section 7. The β_0 rule discovered using the sand ski also holds with a skier's ski on a snow plane. Even when the quality of snow, the inclination of a slope or the skier changes, the β_0 rule holds. On the other hand, based on the historical viewpoint, or description in any text book , based on the talk of instructor, and based on our experiences, we cannot deny our sense of making a ski turn. Thus, as we verify the β_0 rule with more examples, the discrepancy between the skier's sense of making a ski turn and the β_0 rule further expands. We sometimes felt that "*with our ski research methods, elucidation of the ski-turning mechanism may be impossible for us.*" As we continued thinking about this issue for about half a year, we came to believe that "*our sense of making a ski turn may be an illusion*" (early summer in 1984). It did not take much time to prove this idea.

One day I happened to take a bus which was not very crowded from the Daido-chou bus stop in the neighborhood of our university, at 10 o'clock in the morning. As shown in Fig.13, I stood just behind the driver's seat, with legs aligned and my arms extended to hold the hand straps, looking forward. The hand strap is a circular belt hanging from the ceiling. When the bus approached the next bus stop, there was an illegally parked car in front of the bus stop. The driver made a sharp left turn without using the brakes at point K, then

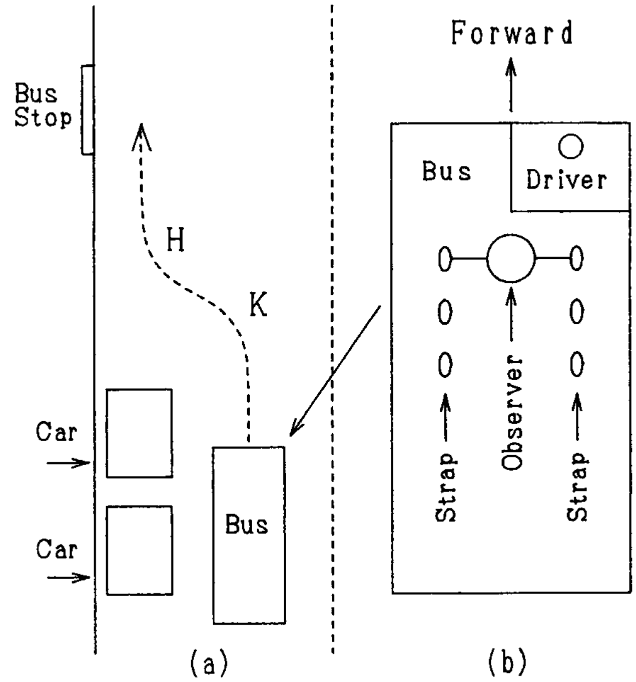

Fig.13　Experiment in a bus on the sense of making a ski turn.
(a) A bus traveling in an inner lane on a road.
(b) A passenger (observer) standing with legs aligned and arms extended to hold the hand straps in a bus, looking forward.

passed point H while braking to arrive at the bus stop. At point K, the radius of curvature of the turn was small and the speed of the bus was high, which generated a large centrifugal force. At that time, my legs moved to the left with the bus. Since the strap did not support my upper body, my upper body almost fell over to the right due to inertial force. Therefore, I twisted my body to the left with my feet as a support. Then, since my body was about to fall in the forward direction due to the braking action, I tried to correct my body position in the backward direction. This series of motions and my perceptions of them were exactly the same as those felt when I attempt to stop skiing at point K by rapid braking after a straight descent, as shown in Fig.14. Namely, the feet move to the left; I make my body turn to the left so as not to fall down. However, I myself feel that I twist my body to the left to make

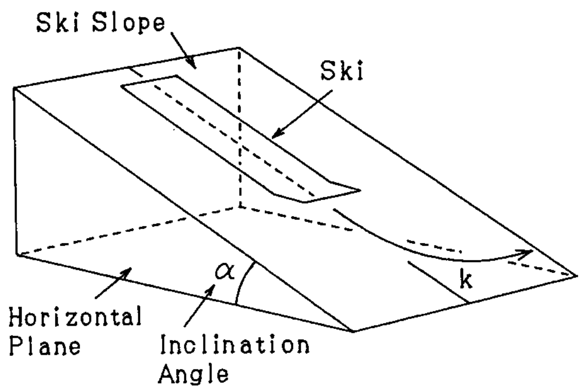

Fig.14　Rapid braking by a skier.