Fig. 7. Locus, δ , θ , R , v , G_c , μ and ψ of the wedeln.

In the case of the wedeln shown in Fig. 7, μ values vary periodically with short intervals. This figure represents a turning descent with a rhythmic pattern.

4.4 Increase in the apparent body weight

In our previous paper, we showed that the skier's sense of making a ski turn during a parallel turn is explained as a *problem in the skier's perception*.⁷⁾ Namely, we had believed that the skier makes the skis turn, but this is an *illusion* on the part of the skier. When the skis turn, the skier makes his/her body turn in the direction of the turning skis, to avoid falling down. According to skiing instruction books, a skier pushes the ski in the direction of his/her feet to make the skis turn.^{4,6)} The truth is that the skier *feels* he/she pushes the skis during turns. As shown in Table I, the apparent body weight of the skier increases 1.1-fold during a turn. The body weight acts in the direction of GS. At this point, the skier must *feel* a 1.1-fold increase in body weight. This apparent increase in body weight may cause the skier to *feel* that he/she pushed the skis.

4.5 Posture of the skier

When a descent is either an upright postured descent or an egg-postured descent, the distance between the skis and the center of gravity in the former, h , is about 1 m and in the latter about 0.5 m. According to Fig. 10, the magnification factor of the body weight, Mc , increases with decreasing h . This phenomenon agrees with our experience that the *feeling of pushing* the skis is greater when the position of our center

of gravity is kept lower during descent.

4.6 Air resistance

We assume that the velocity of the skis is identical to the velocity of the center of gravity of the skier. If we consider here the air resistance of the skier, eq. (1) for acceleration changes to

$$Gc = g(\sin \psi - \mu \cos \psi) - Dv^2/M = (S_1 - S_2)/t^2, \quad (2)$$

where D is the coefficient of air resistance (kgws^2/m^2). Because the skier assumed an almost upright posture during the descents shown in Figs. 3 to 7, we assume that $D = 0.03$.⁸⁾ The mass of the skier, M , is 70 kg, and v is the velocity of the skier (m/s). The coefficient of kinetic friction without considering air resistance is expressed as μ_0 , and eq. (2) becomes

$$\mu = \{\sin \psi - (Gc/g) - (Dv^2/Mg)\} / \cos \psi = \mu_0 - \mu_1.$$

The terms μ_0 and μ_1 that appear in these equations are

$$\mu_0 = \{\sin \psi - (Gc/g)\} / \cos \psi, \quad \mu_1 = Dv^2 / (Mg \cos \psi).$$

The examples of values of μ for ski number 12 in Fig. 3, ski number 12 in Fig. 6 and ski number 17 in Fig. 7 are shown in Table II. When the velocity of the skis, $v \lesssim 6$ m/s, the effect of air resistance on μ is small. Generally, the velocity of the center of gravity of a skier during a turning descent is lower than the velocity of the skis. In addition, because of differences in D due to the effect of the body shape of a skier,

a slight wind, and measurement errors, the absolute values of the range of $\Delta\mu$ (the error of μ) will be 0.01 or less. No effect of air resistance was considered in the values of μ for Figs. 3 to 7.

4.7 Coefficient of kinetic friction, μ

The snow plows are said to be a stable method of descent because of its large braking force. The coefficient of kinetic friction is always large during snow plowing and, as a consequence, the velocity of the skis is low. Table III lists maximum and minimum values of μ , μ_{\max} and μ_{\min} , obtained from our experiments. From the table, we see that as the velocity of a descent increases, μ_{\min} decreases and μ_{\max} increases. This

means, as the velocity of the descent increases, descending parts with large frictional (braking) force are observed. In addition, this table shows that the smaller coefficient of friction, μ_{\min} , coincides with a faster descent. These results agree with our experiences.

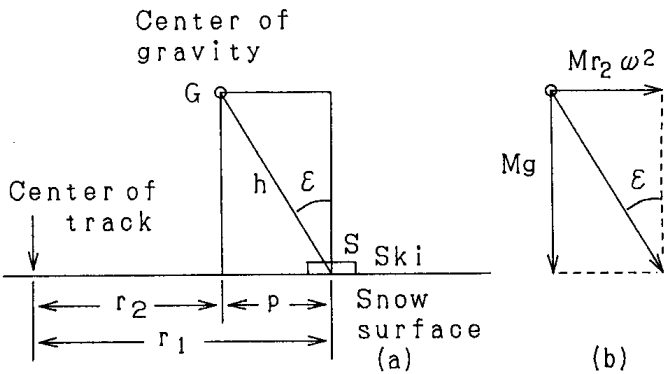


Fig. 9. (a) Diagram of the skier at point A in Fig. 8 observed from the front. The angle of inclination of the center of gravity is ϵ ; h is the distance between the skis and the center of gravity. (b) Body weight of the skier Mg and centrifugal force $Mr_2\omega^2$.

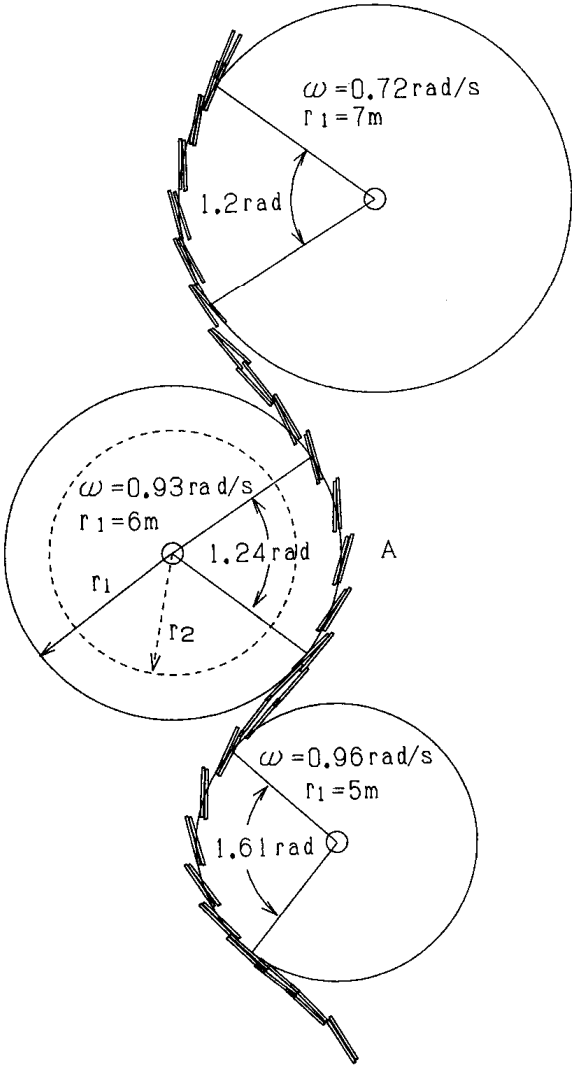


Fig. 8. Three circles on the loci of the skis during the parallel turns shown in Fig. 6.

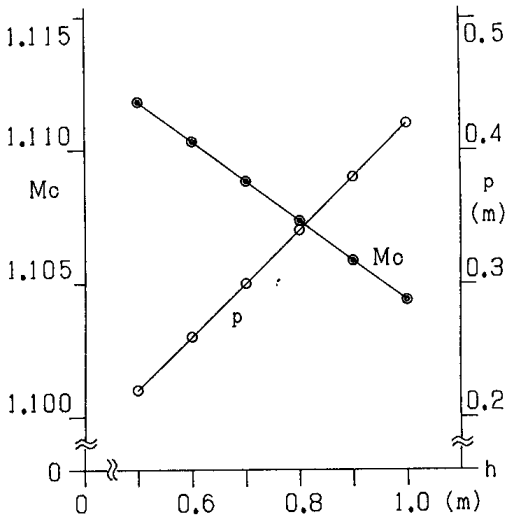


Fig. 10. Change in the magnification factor Mc and p with change in h .

Table II. Effects of air resistance on the coefficient of kinetic friction.

Ski No.	Descent	v (m/s)	ψ (deg)	Gc (m/s ²)	μ_0	μ_1
12 in Fig. 3	snow plow	3.54	5.98	0.61	0.042	0.0005
12 in Fig. 6	parallel turn	5.43	6.09	0.90	0.014	0.0013
17 in Fig. 7	wedeln	6.00	7.00	1.05	0.014	0.0016

Table I. Apparent increase in body weight during a turning descent.

Radius of a turn of the ski, r_1 (m)	7.00	6.00	5.00
Angular velocity of the ski, ω (rad/s)	0.72	0.93	0.96
Distance between the center of gravity and the skis (on a snow plane), p (m)	0.32	0.42	0.40
Inclination angle of the center of gravity, ϵ (deg)	18.39	25.11	23.40
Radius of a turn of the center of gravity, r_2 (m)	6.68	5.58	4.60
Acceleration of centrifugal force, $r_2\omega^2$ (m/s ²)	3.26	5.59	4.24
Velocity of the skis, v (m/s)	4.89	5.45	4.80
Magnification factor of increased body weight, Mc (fold)	1.05	1.10	1.09

Table III. Maximum and minimum values of the coefficient of kinetic friction.

Descent	μ_{\min}	μ_{\max}	v (m/s)
Snow plow	0.05	0.2	3–3.5
Stem turn	0.02	0.2	3.5–4.5
Parallel turn	0.01	0.3	4–5.5
Wedeln	0.01	0.3	5–6.5

4.8 Causes of frictional force during ski descent

In addition to the frictional resistance between the skis and the snow surface, the frictional force during a ski descent includes snow-removal resistance at the tips of the skis and during edging of the skis. Accordingly, the coefficient of kinetic friction μ includes all of these factors. Bowden and Hughes⁹⁾ explained the frictional resistance between skis and snow using frictional melting. Kinoshita¹⁾ and Shimbo²⁾ measured the values of μ to be approximately 0.05–0.01.

Shimbo²⁾ measured the values of μ while reducing the snow-removal resistance effect. The obtained μ values varied depending on ski velocity, ski load, snow temperature and quality of the ski material (including the variation of scratches on the ski surface). In our experiment, the ski velocity was 2–7 m/s. Assuming that the ski area is $10 \times 180 \text{ cm}^2$, the average ski load becomes 40 g/cm^2 ; therefore the ski load will vary between $20\text{--}60 \text{ g/cm}^2$ considering the effects of ski operation by the skier through flexing and extending his knees. During our experiment, snow temperature, snow quality and ski material were considered to be constant. Judging from the experimental values obtained by Shimbo,²⁾ the range of μ values in our experiment, according to changes in ski velocity, ski load, snow temperature, snow quality and ski material, should be 0.01 or less. However, the values of μ obtained in the actual experiment were large, 0.01–0.3.

In our experiment of parallel turns, the minimum value and the maximum value of μ are obtained when the ski angle $\delta = 0^\circ$ and $\delta = \text{maximum}$, respectively. δ is small when the ski is edged toward the downhill side to perform a downhill turn. During such a turn, the edging angle, with respect to

the slope, decreases, resulting in small resistance due to edging. In contrast, δ is large when the ski is edged toward the uphill side to perform an uphill turn. The edging angle, with respect to the slope, increases, leading to a large resistance due to edging.^{7,10)} In ski descent with other types of turning, the relationship between δ and the edging angle is similar to that in the parallel turn. Therefore, small values of the coefficient of kinetic friction are considered to be due mostly to the frictional force between the ski and the snow surface. In contrast, large μ values are thought to also include resistance resulting from a large edging angle.

5. Conclusion

During turning descents, when the skis are pointed in a direction close to the fall line FL, they are descending in a downhill turn, during which the value of μ is small and dependent on the frictional force between the ski and the snow surface. When the skis are aligned in a direction largely different from FL, they are descending in an uphill turn, during which the value of μ is large and dependent on the resistance due to the edging.

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