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ISEA 2008, just before the summer Olympic games!

What a fantastic opportunity to present a compilation of more than 160 articles talking about sports engineering, analysing the coefficients of friction between the balls and the rim and back-board for leather and synthetic basket balls, extracting the aerodynamic force data during real ski jumping flights, optimizing new prosthesis of the lower human leg, analysing the golf ball spin rate after impact, analysing the most common injury in sport climbing using eight fresh dozen cadaver fingers, describing the heat transfer in footwear using finite elements, measuring the aerodynamic performance of cycling time trial helmets, etc, …

What a challenge too to be honest!
A huge diversity of articles, top level contributions to sports engineering.

Today the world is convinced sport is not only fun but economically a sector, a multi sector, which is not only growing if you only take into account the total turnover but is becoming one of the fast growing business.

Sport is not any more reserved for top sporters who want to maintain a certain level in some disciplines, it became a new philosophy of life, a new trend, a way to cope with aging population, with the reality of the society today.

Our every day life is concerned with sport or sport derived products or services, it is in our shoes, our suits, our car, our bike, at home, when we eat, when we drink, when we sleep, relax, when we look at TV for international events, when we listen, watch the news, for fun. The sports engineering community as it was noted two years ago keeps growing.

We have to admit it was a very difficult task to review all the contributions and to come down to 150 articles; It was very difficult too to allocate reviewers to contributions because a lot of articles were proposing not only scientific contributions but also engineering solutions and methodologies.

Some groups of articles could have been selected as a basis for a workshop in itself!

In front of such a diversity of contributions we have decided not to group the articles by families, by themes, by keywords, by branches, by sports, by subjects, by numbers of contributions but we decided to regroup it in two different volumes without any introduction which we thought would not bring anything to the readers, just proposing the articles in a natural order creating of course some surprises, but it was a choice!

Of course there is a table listing the articles with their authors and co-authors and the programme will indicate every time the article number.

Complex to read? Difficult to apprehend? We thought it would give the best way to understand the complexity of sports engineering today; An article about football in a ball section of proceedings, in the shoes section, in the field surface section, in the injury section, in the training part, in the video group, in the sliding effect paragraph, in the referee point of view chapter, in the leather section may be, why not the aerodynamics or the finite elements analysis, may be in the professional sports section or the leisure, the TV business, the star system, …

So many possibilities, we just did it in the way we were convinced would be the most open!
What we wanted to do is to provide the readers with the best sports engineering contributions in 2008, before the biggest sports event on earth, the olympic games, in front of 5 billions telespectators who will enjoy the show and for many of them start again sporting, or just start a new sport, realising what they can do, discover a new passion, using in any case the brain storming of the world of engineering contributors to improve our every day life.
This is the magic of sport!

Margaret ESTIVALET & Pierre BRISSON
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Measurement of the Forces on Ball in Flight Using Built-in Accelerometer (P138)

R., Koyanagi¹, Y., Ohgi²

Abstract: In this study, tri-axial accelerometer was installed in a ball to measure the aerodynamic forces during the ball’s flight. The control experiments to validate were conducted besides the pitching experiment, to examine ball linear or angular velocity components independently. These were performed using a turntable and free fall test, respectively. The acceleration data of the throwing experiment showed a semi-sinusoidal wave pattern. On the other hand, this wave pattern was not observed in the acceleration data of both the rotational table experiment and free-fall experiment. It was revealed that the change of the orientation vectors of the gravitational acceleration and the translation acceleration on the sensor coordinate system caused the sinusoidal acceleration pattern.

Keywords: Accelerometer, aerodynamic force, flying ball, baseball.

1- Background

The measurement of the aerodynamic forces during the flight of the ball is one of the major topics in the fluid mechanics in sports. The wind tunnel test and the image analysis are mainly used to measure of the fluid forces. However, both of the methods have some difficulties. The experimental condition of the wind tunnel is different from the actual flying ball in the point that the ball is fixed. As for the image analysis, it is difficult to observe flying ball continuously. In this research, the author proposes a new methodology to measure the aerodynamic forces by the built-in accelerometer. To validate the acceleration components, controlled experiments in the laboratory were conducted in addition to the pitching experiment. The controlled experiments were described as follows, 1) Rotational table experiment, 2) Free fall experiment. The ball moves the gyration without translational acceleration in the rotational table experiment, and the ball moves the translational movement without rotational condition in the free fall experiment.

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2. Room No. o206, 5322 Endo, Fujisawa, Kanagawa, JAPAN, 252-8520, Associate Professor, Graduate School of Media and Governance, Keio Univ. - E-mail: ohgi@sfc.keio.ac.jp
2 Methods

2.1 Equipment

Figure 1 shows the wireless piezo-electric acceleration sensor, W988-H (Hitachi Metals Co. Ltd). The measurement range of this accelerometer is ±3g (±29.4 (m/s²)). The sampling rate of the accelerometer is 200Hz. The measured acceleration data are transmitted to the receiver by wireless. The accelerometer was capsulated by the FRP (fiber-reinforced polymer) and subereous case. The diameter and mass of the sensor ball is similar to the baseball ball.

![Wireless accelerometer](image1)

**Figure 1 - Wireless accelerometer.**

![Overview of the sensor baseball](image2)

**Figure 2 - Overview of the sensor baseball.**

**Table 1 - Comparison between baseball and experiment balls.**

<table>
<thead>
<tr>
<th></th>
<th>Baseball ball</th>
<th>Experimental ball</th>
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<tbody>
<tr>
<td>Mass (kg)</td>
<td>0.1417-0.1488</td>
<td>0.148</td>
</tr>
<tr>
<td>Radius (m)</td>
<td>No regulations</td>
<td>0.035±0.002</td>
</tr>
<tr>
<td>Circumference (m)</td>
<td>0.229-0.235</td>
<td>0.220±0.012</td>
</tr>
</tbody>
</table>
2.2 Experiments

2.2.1 Pitching experiment

The author conducted a real pitching experiment. A subject performed ball pitching using the ball built-in wireless piezo-electric acceleration sensor. The closed up release point image was acquired using two high speed cameras (1000Hz). The synchronization between the high speed cameras and the accelerometer was accomplished by the contact switch. The distance of the ball's flight was about 17 (m). The subject pitched straight ball in this experiment.

2.2.2 Rotational table experiment

The sensor ball was rotated with a turntable and its acceleration was acquired. The author set the magnitude and the time of the angular velocity acting to the ball. The magnitude of the angular velocity increased from $2\pi$ (rad/s) to $10\pi$ (rad/s) by $1\pi$ (rad/s) (Fig. 3). Each angular velocity acted to the ball for five seconds. The z axis of the acceleration sensor was corresponding to the rotation axis and the author observed x axis of the accelerometer. In this experiment, the authors examined the acceleration of the rotating ball with no translational movement.

![Figure 3 - The change of angular velocity in the rotational table experiment.](image)

2.2.3 Free fall experiment

The sensor ball was dropped from 7.5 (m) height without rotation. This experiment was performed indoor condition avoiding the wind effect. The positive z axis of the accelerometer was corresponding in the direction of the fall.

3 Results

3.1 Pitching experiment

The acceleration data obtained in the pitching experiment had four components, such as the gravitational acceleration, the translational acceleration, the centrifugal acceleration and tangential acceleration [01]. Therefore, the equation can be rewritten as follows.

$$A = a_i + g + \omega_B \times (\omega_B \times (-r_s)) + \dot{\omega}_B \times (-r_s)$$

(1)
Where, \( A \) indicates measured acceleration by built-in accelerometer in the baseball, \( g \) indicates gravitational acceleration, \( \mathbf{r} \) indicates distance vector of the ball’s axis, \( \mathbf{a}_t \) indicates translational acceleration acting on the accelerometer, and \( \omega_B \) indicates angular velocity of the ball.

The sum of these four components is output. Gravitational acceleration, translational acceleration, centrifugal acceleration and tangential acceleration are output from the accelerometer.

Figure 4 shows the acceleration data acquired in the pitching experiment. Figure 5 shows its flight phase shown in Fig. 4.

![Figure 4 - The waveforms of the acceleration at the pitching experiment.](image1)

![Figure 5 - The acceleration during the flight.](image2)

The FFT analysis was conducted to reveal the frequency characteristics of these wave patterns. Figure 6 shows the power spectrum of the acceleration shown in Fig. 5.

From Figure 6, the power spectrum of the acceleration data had its peak in about 15 (Hz) except DC component.

Therefore, the periodic change of the acceleration data in the pitching experiment was indicated.

![Figure 6 - The power spectrum of acceleration in Figure 5.](image3)
3.2 Rotational table experiment

In the rotation table experiment, $a_t$ must be 0 because the translational movement doesn’t exist on the ball. The author set that the observed acceleration axis is perpendicular with the direction of the gravitational acceleration. Therefore, the acceleration output by this experiment can be simplified as follows.

$$\mathbf{A} = \mathbf{\omega}_B \times (\mathbf{\omega}_B \times (-\mathbf{r}_g)) + \dot{\mathbf{\omega}}_B \times (-\mathbf{r}_g) \quad (2)$$

Figure 7 shows the x axis acceleration acquired by the rotation table experiment.

![Figure 7 - The x-axis acceleration in rotational table experiment.](image)

Figure 8 was the power spectrum of the acceleration shown in Figure 7 by FFT.

![Figure 8 - The power spectrum of the x-axis acceleration in the turntable experiment](image)

Figure 8 indicates no periodic change of the acceleration which was observed in the pitching experiment.

3.3 Free fall experiment

In the free fall experiment, the centrifugal and tangential acceleration must be 0 because the rotational movement doesn’t exist on the ball. Therefore, the acceleration output by the free fall experiment can be simplified as follows.

$$\mathbf{A} = a_r + g \quad (3)$$
Under this configuration, the direction of the air drag is opposite to gravitational acceleration. When there is no air resistance, the absolute value of the acceleration signal must be 0 because of the counterbalancing acceleration by the free fall. Therefore, the change of the acceleration from zero is thought to be an air resistance.

Figure 9 shows the z-axis acceleration acquired in the free fall experiment. The waveform showed approximately zero when the ball was dropped off, and the acceleration decreased in proportion to the time squared.

![Figure 9 - Waveform example of the z-axis acceleration in the free-fall experiment.](image)

The power spectrum was calculated for the comparison with the pitching experiment. Figure 10 shows the power spectrum of acceleration shown in Figure 9.

![Figure 10 - The power spectrum of z-axis acceleration in the free fall experiment.](image)

From Figure 9, no remarkable peak spectrum can be seen in the free fall experiment.

### 4- Discussion

The turntable experiment and free-fall experiment, no remarkable spectrum peak observed in the pitching experiment was observed on the FFT results. Therefore, when the ball flies with translational and rotational movement at the same time, the sinusoidal wave pattern appears. No external force except the aerodynamic forces and gravity influences the translational acceleration of the flying sensor ball. Therefore, the author
supposes that the aerodynamic forces which influence translational movement of the ball in the pitching experiment. When a global coordinate system was fixed on the ground, the direction of the aerodynamic forces and gravitational acceleration are constant with respect to the global coordinate system. On the other hand, the direction of the aerodynamic forces and gravitational acceleration on the sensor coordinate system rotate, because the acceleration sensor rotates itself during its flight phase. The centrifugal force depends on a radius between the center of rotation and the sensor and the angular velocity. Therefore, the direction of the centrifugal force on the global coordinate system always changes. And on the sensor coordinate system it is stable and pointing to the center of rotation. The gravity and the aerodynamic forces appear as the amplitude of the wave on the acceleration. On the contrary, the centrifugal force is output to the acceleration as the drift level of the wave.

The obtained acceleration in the pitching experiment showed the periodic change. It is thought that the periodic change of the acceleration waveform shows the influence of gravity and the aerodynamic forces on the ball. When a resultant vector of the aerodynamic forces and gravity have changed periodically, it was thought that one single cycle of the waves indicated one rotation of the ball in the pitching experiment. Therefore, the angular velocity could be estimated by measuring the time of one cycle.

For our future work, the authors would like to distinguish each acceleration component to estimate the rotational axis and the aerodynamics forces of the ball.

5- Conclusion

The acceleration time histories in the pitching experiment showed the sinusoidal curves. The periodic change of its magnitude was observed. According to different types of experiment, both the free fall experiment and the rotation table experiment, the author quantified translational and rotational effects. According to the result of the rotational table experiment and the free fall experiment, the acceleration component of each force in the pitching experiment was estimated. The gravity and the aerodynamic forces were indicated as the amplitude of the acceleration wave. On the contrary, the centrifugal force was indicated as the DC component of the acceleration wave.

6- Reference


Topics: Ski & other Winter Sports.

Abstract: A style of ski jumping has been changed from a parallel style to the present V-style. The glide ratio varies in jumping styles. The glide ratio and the pitching moment of different jumping styles were examined with wind tunnel experiments by using a replica of a human figure. Opening angle between skis, spacing of skis and a posture of the figure were defined as parameters. It was observed that the glide ratio of the V-style was higher than that of the parallel style at the same angle of attack. A stoop shouldered style was also effective to increase the glide ratio. Differences of the flow field among jumping styles were observed with cotton balls and a tuft method in a smoke wind tunnel. While strong but narrow band downwash was appeared in a wake of the parallel style, wide but weaker band downwash was seen in that of V-style.

Keywords: Ski Jumping, V-style, Posture, Glide Ratio, Flow Visualization.

1- Introduction

The V-style is a style of the present main current in the ski jumping. In the flight phase, the aerodynamic characteristics of the posture control jumping distance. The V-style posture used to be considered as a disordered form so that style points were marked off. However, there was an advantage of 4 meters or more in distance to compensate for the marked off points. That was how the V-style became the main current nowadays. A scientific research on the ski jumping started with wind tunnel experiments with a small size replica by Tani et al (1951). Based on the experimental results, they proposed a parallel style, the previously popular jumping style, in which a jumper’s hands were placed on the side of the body. A jumping style before the parallel style was a parallel style with jumper’s hands extended over the head. An average jumping distance had improved greatly because of their study. Experimental studies on ski jumping with a
human body or a human sized dummy in a large wind tunnel has been a primary concern for the recent years to agree the Reynolds number to the reality. And flight simulation was conducted based on those experimental results. Watanabe (1993) investigated aerodynamic characteristics of opening angles of ski boards of the V-style in a large-scaled wind tunnel using a real human. Müller (1996) experimentally examined aerodynamic changes due to posture changes during the flight phase with a human in a large-scaled wind tunnel and compared with field measurement and with computer simulation. Seo et al (2004-1, 2), one of the authors, conducted experiments with a real human in a large-scaled wind tunnel. They examined aerodynamic characteristics and did the optimized calculations in order to extend flight distance by changing ski-opening angles of the V-style during the flight. They gave us some suggestion to fly further. Concerning the experiments in a large-scale wind tunnel, simplified and limited experiments were conducted because various parameters existed in the human body experiment after-mentioned. Therefore, we performed the aerodynamic experiments to acquire an optimal posture to fly further by investigating a lot of various styles and postures with a scaled figure. On the other hand, flow visualization helps to understand the flow field around a ski jumper and to improve the specification of drag and lift forces. Masunaga and Okamoto (1993) captured longitudinal vortices behind legs and skis on a parallel style by the disturbance of tuft with tuft grid experiment in a circulating water channel. These vortices showed the generation of lift and increase of drag. We also visualized air flow around a ski jumper to understand the flight phase.

Jumping distance is related to a height of a take-off ramp and glide ratio. Glide ratio (Reach/Height), also called as a lift-to-drag ratio, is an aviation term that refers to a distance which an aircraft moves forward for any given amount of lost altitude (the cotangent of the downward angle). Concerning ski-jumping games, the height of take-off ramps is fixed. Therefore, a posture which has high glide ratio is desirable for ski jumping. However, stability during flight phase is also required. A negative pitching moment initiates unbalance of the posture because raising up force of the upper body is necessary to maintain the posture during the flight in this case. Grasp of positive pitching moment is important to keep a stable flying posture. That is to say that it is
indispensable to ski jumping to choose an appropriate jumping posture with a high glide ratio and a positive pitching moment. Various jumping postures were tried on a figure of about 1/5 in scale and lift and drag characteristics were obtained using an advantage of modal test in this research. The air flow around the scaled figure was also visualized to understand the air flow during the flight phase.

2- Method
A scaled figure (L=259mm) was made based on the data of Daito Takahashi, a player in the Japan’s Olympic team. This was a figure replica reproduced accurately with his ski size (250cm) and the binding position based on his height, weight (168cm, 61kg) and Body Mass Index (FIS regulation, 2007). In addition, we defined angle of attack $\alpha$ composed of skis and wind velocity $U$, inclination angle $\theta$ of skis and legs, thorax angle $\gamma$ between the chest backbone and legs, abdominal angle (lower back bend angle) $\sigma$ between the lower back and legs and head up angle $\eta$ between the head and legs indicated in Figure 1(a), ski opening angle $\lambda$ between each V shaped skis, spacing $h$ of each ski indicated in Figure 1(b), arm angle $\mu$ between an arm and a trunk and dihedral angle $\delta$ of skis in Figure 1(c). Drag and lift forces were measured by a three component load cell. The back of the hand was arranged facing to the front so that ski jumpers might do so. All the experiments were conducted at a wind velocity of 20m/s, that is to say, on Reynolds’ number $Re=5.12 \times 10^5$ as wind velocity $U^*\text{ length of skis }/\nu$. This was equivalent to 1/8-1/10 of the actual Reynolds number. Firstly, a parallel type was examined to check influences on front inclination angle: $\theta$, opening angle $\mu$ of the arm, lower back bend angle: $\sigma$, thorax angle: $\gamma$ and head-up angle: $\eta$. Secondary, we investigated the optimal opening angle $\mu$ of V-type referring to the most suitable angles obtained from the experiments with the parallel type above. Moreover, lift $L$, drag $D$, and pitching moment $M$ were normalized by dynamic pressure, ski projection area $S$ and ski length $l$. coefficient of lift $C_L$: $C_L = L/(1/2\cdot \rho v^2 S)$, drag coefficient $C_D$: $C_D = D/(1/2\cdot \rho v^2 S)$and moment coefficient $C_M$: $C_M = M/(1/2\cdot \rho v^2 Sl)$ were estimated by angle of attack $\alpha$. In addition, in order to examine factors to generate aerodynamic characteristics of each parallel and V-style, the flow field was visualized in a wind tunnel with three methods; a smoke wind tunnel, a tuft, and a method with cotton balls. The experiments with a smoke method were conducted at Reynolds number $Re =5.12\times10^4$. The other experiments were conducted at $Re =5.12\times10^5$, defined by the characteristic length which was the ski length $l$.

3- Result and Discussion

3.1 Aerodynamic Specification
Both Figure 2 and 3 are the experimental data in the parallel style. Figure 2 shows the effect of posture angle by glide ratio at angle of attack $\alpha$ in a condition of $h=1W$ where ski spacing is equal to ski width with forward inclination $\theta = 10^\circ$. The trunk becomes parallel to the ski by $10^\circ$ with lower back bend angle $\sigma=10^\circ$. In case of $\gamma = 10^\circ$, where the
back bone becomes almost a straight line to the legs, glide ratio line draws a gentle curve and reaches to the maximum of 0.96 at about $\alpha=17^\circ$. In case of so-called stoop-shouldered posture with $\gamma=20^\circ$, the glide ratio curve rises straight to the maximum point area. When the head-up angle is $\eta=10^\circ$, glide ratio reaches to the maximum of 1.13 at $\alpha=13^\circ$. With the head-up angle of $\eta=25^\circ$. The maximum of 1.07 is at about $\alpha=17^\circ$. This fact indicates that the stoop-shouldered posture generates higher glide ratio than the straighten posture. That is because the body and ski take an airfoil shape as a whole with the stoop-shouldered posture. The drag force decreases and the lift force increases because the flow separation area may decrease at the back corresponding to a suction surface of the wing. Consequently, the glide ratio increases relatively. The effect of arm-to-trunk angle is indicated in Figure 3. The maximum points of glide ratio are $(\alpha, L/D) = (14^\circ, 1.13)$ and $(15^\circ-18^\circ, 1.15)$ at each arm-to-trunk angle of $\mu=0^\circ$, $\mu=10^\circ$. The maximum glide ratio at $\mu=10^\circ$ is slightly higher than the other. When $\mu = 15^\circ$ where an arm is apart from the trunk, the glide ratio becomes lower than the two above. When the arm is close enough to the body, they are considered as part of the body, and the load of projection area is increased. This causes an effect of increasing the lift. On the other hand, when the arm is apart from the body to some degrees, the effect of increasing the
projection area is lost, and the arm no longer increases the lift. The glide ratio decreases
consequently. Therefore, the arm should be placed nearby or on the body. Based on these
results, the stoop posture at $\eta=20^\circ$ with the forward inclining angle of $\theta=10^\circ$ and the
arm opening angle of $\mu=10^\circ$ was adopted for the following experiments in V-style
posture.

Figure 4 indicates an effect of V-style ski-opening angle $\lambda$ to the lift coefficient. $C_L$
curves are compared in the following cases: parallel, $\lambda=0^\circ$, V-style in $\lambda=20^\circ$, $\lambda=35^\circ$ and
the reverse V-style, -25°. With increasing angle of attack $\alpha$, the lift coefficient $C_L$ of
jumping postures except for the reverse V-style, $\lambda=-25^\circ$, increases monotonously. The
angle of attack on the maximum of $C_L$ shows more than $\alpha=30^\circ$. In case of two dimen-
sional wings, it is generally is less than 20°. Figure 4 shows each style does not to stall
easily even in large angle of attack compared with those of two dimensional wings. The
lift force coefficient of a V-style jumping posture and a reverse V-style jumping posture
is larger than that of a parallel jumping posture (\(\lambda=0^\circ\)) in the same angle of attack
because the actual projection area increases. The coefficient of lift of a reverse V-style
jumping posture is smaller than that of a V-style jumping posture in more than 18° of
$\alpha$. The lift gradient of V-style postures is larger than that of a reverse V shape posture.
The curves of $C_L$ gradient at $\lambda=20^\circ$ and $\lambda=35^\circ$ of V style is almost the same degree.
Similarly, Figure 5 indicates the consequence of opening angle of V-style of ski in the drag coefficient. $C_D$ also becomes larger than that of a parallel style for that of a V-style as the projection area increases. With increasing angle of attack, the drag force coefficient also increases monotonously mostly like the lift coefficient. The drag coefficient of the reverse V-style posture, $\lambda = -25^\circ$, indicates larger than that of the parallel posture, and the drag coefficient of the V-style posture is larger than that of a reverse V-style posture in more than 18° of $\alpha$. And the drag coefficient of the V-style posture in $\lambda = 20^\circ$ is indicated larger than that in $\lambda = 35^\circ$.

The relation among the V-style opening angle of ski on glide ratio is shown in Figure 6 based on these. The value of the maximum points in the glide ratio were $(\alpha, L/D) = (16^\circ, 1.15), (16^\circ, 1.21), (15^\circ, 1.34), (13^\circ, 1.18)$ respectively. They were found to become larger with increasing the V-style opening angle $\lambda$ than parallel clearly. In case of the reverse V-style, $\lambda = -25^\circ$, the glide ratio was more predominant than the other styles in low angle of attack, less than 10°. It was almost the same degree with parallel styles in more than 10° of angle of attack. A specific rise of glide ratio can be seen again in more than 30° of $\alpha$ in this reverse V-style. In the V-style jumping posture, the jumping at the angle attack from 13° to 25° is desirable because of its high value of the glide ratio.

The relation between the pitching moment coefficient $C_M$ and the angle of attack $\alpha$ is shown in Figure 7. In case of the parallel style, an unstable state of negative $C_M$ is seen when the angle of attack is less than 6°. This unstable state means a possibility for the ski jumper to fall or stall. The state turns to stable and tends to increase monotonously at more than 6° of angle of attack. The pitching moment coefficient is positive at any angle of attack in V-style and in reverse V-style. In this stable state where the pitching moment coefficient is positive, the ski jumper can maintain the forward inclined posture being well balanced in the air. In case of the reverse V-style at more than 30° of $\alpha$, a sudden irregular change in $C_M$ appears. It might be difficult for the jumper to keep his balance compared with the monotonous increase in $C_M$ like with the other style.

### 3.2 Specification of the Flow Field

Figure 8 shows smoke streak lines in a smoke wind tunnel at V-style opening angle $\gamma = 35^\circ$ and angle of attack $\alpha = 25^\circ$ with the stoop-shouldered posture at $\gamma = 20^\circ$. It is seen that the flow line flows along the back of the replica without flow separation. It means that the jumper is not stalling. Obviously, the jumper’s posture also affects jumping distance besides ski styles. Mechanism of lift generation in airfoil is classified into two sorts, two-dimensional wing and three dimensional one. Flow separation causes a stall in 2-D wing. On the other hand, flow separation and three-dimensional longitudinal vortices generate lift forces in 3-D wing like a delta wing. Therefore, lift forces can be maintained even at high angle of attack in 3-D wing. Because of small aspect ratio of a jumper with skis, the occurrence of large tip vortex can be expected at the outer edge of skis. Although a wing stalls at less than angle of attack=20° in 2-D wing in general, a lift-curve of the parallel style (a solid line shown in Figure 4) indicates that stall does not occur even at angle of attack=35°. Therefore, the flow field around the jumper with skis as a whole is expected to be three dimensional. And the aspect of lift curve can be expected the generation of three-dimensional longitudinal tip vortices. Figure 9 visua-
lized the tip vortex and the streamlines in a V-style posture, where V-style ski-opening angle $\lambda = 35^\circ$, forward inclination $\theta = 10^\circ$ in a smoke wind tunnel. The longitudinal vortex occurs from the pointed end of the ski front, which circumvent from underneath to upside the ski board, but the flow around the other part of the ski was two-dimensional against the cross-section like 2-D wings.

Figure 10 - Wake configuration of parallel style.

Figure 11 - Wake configuration of V-style.

Figure 12 - Downwash flow of parallel style.

Figure 13 - Downwash flow of V-style.

Figure 14 - Actual picture of ski jumping (Reath, 2002).

Figure 10 and 11 show longitudinal vortices created into a slipstream visualized with cotton balls tied with a thin fishing line from upstream. They show cross-sectional views of the flow field behind the figure. Trajectories of the cotton balls form a bottom of a conic shape with an ellipse in cross-section in the parallel style in Figure 10. The left and right tip vortices are produced at the outer side edges of the parallel skis which have long
wing tips. On the other hand, Figure 11 shows circular trajectories with a conic bottom cross-section in the V-style. The three-dimensional flow of the tip vortex is created at the point end of the ski front and circumvent outside from underneath to upside the ski board. The left and right tip vortices associate with each other and the flow appears as downwash right behind the figure replica. Strength and area of the downwash are visualized with a tuft method in Figure 12 and 13. Spacing of each tuft is 15mm. Figure 12 shows the aspect of downwash in the parallel style. Every tuft in two rows behind the replica faces downward as if pasted on the tuft mesh. It shows that narrow but strong downwash is generated in the parallel style. On the other hand, Figure 13 shows that tufts in four rows just inclined downward in the V-style. It means that the speed of downwash is less but the effective area is broader in the V-style. Considering downwash as a reaction of the momentum against the lift, the lift of ski jumping is generated by the downwash caused by three-dimensional tip vortex. With weaker downwash projected at broader area, skis seem to be more stable than with stronger downwash at narrower area. Although verification has not been done yet, the V-style seems to be more stable in rolling motion by downwash than the parallel style.

4- Comparison with actual jumping posture and experimental result

Looking at an actual jumping posture in flight, ski boards are inclined upward as shown in Figure 14. Figure 6 indicates that the maximum glide ratio of the V-style ranges at angle of attack to the ski of $13^\circ \leq \alpha \leq 25^\circ$. However, the angle of attack estimated from the actual picture is from $30^\circ$ to $40^\circ$. Of course, it needs to take photography conditions into consideration, but it is necessary for ski jumpers to lean more forward by overcoming their fear to fall in order to achieve the theoretical optimal jumping distance.

5- Conclusion

The aerodynamic specification of the ski-jumping posture: lift, drag and pitching moment were investigated by conducting wind tunnel experiments. The relation between the flow field and postures was also examined by flow visualization. As a result, the following facts were confirmed.

1. Lift increases monotonously at any style with increasing the angle of attack up to at least $35^\circ$.
2. Drag also increases monotonously at any style with increasing the angle of attack up to at least $35^\circ$.
3. The advantage of a V-style against a parallel style was confirmed as high glide ratio.
4. The maximum glide ratio was obtained at the opening angle $\mu=35^\circ$ in our experiments.
5. V-style ski-jumping form is easy to maintain the forward tilt posture with the positive pitching moment at any angle of attack.
6. Stoop-shouldered posture increases glide ratio than straight posture because the stoop-shouldered posture creates less turbulence at the back of the skier.
7. Flow visualization around ski jumping indicated that the lift generation mechanism was three-dimensional.

6- References

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Quantification of the Grip Difficulty of a Climbing Hold (P142)

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Topics: Climbing and Mountaineering.
Abstract: The difficulty of a climbing hold was attempted to be quantified based on fractal dimensions. The difficulty was confined to the change of a single value, namely the inclination of the grip surface, by increasing the overhang of the wall. Sixteen climbers of different experience levels participated in this experiment and had to climb a route equipped with an instrumented hold repeatedly until they failed at a specific degree of overhang. The force-time signals served to calculate the Hausdorff dimension. Subsequently, the Hausdorff dimension was normalised to force and time by a power fit. The normalised Hausdorff dimension increases significantly with the difficulty of a climbing hold, which is – in this study – the inclination of the grip surface. Weaker climbers produced larger normalised Hausdorff dimensions. If the climber fails at the instrumented hold, the force-time signal shows smaller normalised Hausdorff dimensions. Fractal dimensions are a suitable tool to quantify the difficulty of a hold if applied with caution.
Keywords: sport climbing; instrumented climbing holds; perception; force analysis; Hausdorff dimension.

1- Introduction
The difficulty of a climbing route depends on the shape (difficulty to grip) and the sequence of holds (difficulty of movements), as well on the inclination of the wall. The difficulty to grip a climbing hold is related to the shape factor, which summarises the size, the curvatures, the surface texture, and the type of grip (crimp, open hand, pinch, finger pocket, etc.). The most difficult part of the route, the crux, decisively influences the grading. Route grading, however, requires extensive experience and is simply a matter of perception. Other than perception, no means for route grading are available. Different scales were developed in different countries and thus no uniform scale is avai-