Simulation of Snowboarding on Snow Surface Modelled with Particle Elements

Tatuya Yoshida[1], Akihiro Hojo[2] and Humiyasu Kuratani[1]
[1]*Faculty of Engineering, University of Fukui, 3-9-1 Bunkyo, Fukui-shi, Japan*
[2]*Graduate school of Engineering, University of Fukui, 3-9-1 Bunkyo, Fukui-shi, Japan*

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Abstract: One approach for an efficient development of snowboards is quantification of prototype performance. A simulation model which represents the discrete behaviour of snow with particle elements is developed to evaluate snowboarding performance of prototypes. The particle behaviour is calculated using the discrete element method (DEM). A snowboard is considered to be a rigid body in the simulation. Four snowboards with different sidecuts are modelled to evaluate the influence on the turn. The simulation is able to confirm the difference of trajectory due to the sidecut radius. The smaller sidecut radius increases the attack angle of the board. As the result, lateral force acting on the board increases and the turn become sharply.

1 INTRODUCTION

Several analytical and experimental studies have found that the mechanical properties of skis and snowboards affect their performance (Brennan et al., 2003; Buffinton et al., 2010). In the actual design process for skis and snowboards, designers consider the material used, the manner in which it is laminated and the board thickness. Many prototype models are evaluated for static and dynamic properties, such as bending and torsional stiffness, natural frequency and damping in the laboratory. After the lab testing process, test riders evaluate the prototype boards based on subjective opinions about the performances under various conditions. This process is time-intensive and costly because of the necessity to make many iterations of prototypes. Moreover, manufacturers generally rely on a trial-and-error procedure. In field tests, it is difficult to evaluate different prototypes under the same conditions. This makes the performance results from field tests difficult to evaluate quantitatively.

One approach to solve this technical problem is the development of numerical simulations that model key aspects of snowboarding performance. In a simulation, the snow surface can be modelled with identical conditions for quantitatively testing each iteration of a design. Moreover, the simulation makes it possible to quantitatively predict the manner in which changes to the board design will affect it's performance. This allows us to easily realise the desired characteristics of the snowboard and can reduce the time and costs needed for prototyping snowboard designs: a first prototype is edsigned based on simulation results and the model shows gideline of design modification after evaluations of test riders.

Skis and snowboards push snow away from the board surface as they slide down a slope. Some snow is scattered while another type snow is deformed and packed. Although one study (Federolf et al., 2010) represented snow as a continuous body using the finite element method, a simulation model that considers both the discrete behaviour and large deformation of snow may be necessary when the deformation of the snow surface becomes large. The finite element method is not suitable to reproduce snow in some case because Skis and snowboards turn carve snow and grooves with their edge.

In this study, we develop a simulation model to reproduce the discrete behaviour of snow by calculating interaction forces between a board and snow particles. We evaluated the influence of the sidecut radius on the turning behaviour using the simulation. The reaction force from slope, rotation angle and attitude of the board affect the snowboarding turn and are evaluated by the simulation.

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2 METHODS

2.1 Snow Model

In this simulation model, snow is modelled as particle elements. The particle behaviour is calculated using the discrete element method (DEM). Based on the Voigt model shown in Figure 1, the model calculates the contact forces between snow particles. In Figure 1, k is the spring coefficient, η is the damping coefficient and μ is the friction coefficient. The subscript n indicates the normal direction, and the subscript t indicates the tangential direction. By setting these parameters appropriately, the DEM can reproduce the discrete behaviour of snow. The motion equation that expresses the behaviour of particle i is shown in the following equation.

$$m_i \frac{d^2\mathbf{x_i}}{dt^2} = m_i\mathbf{g} + \sum \mathbf{F_{nj}} + \sum \mathbf{F_{tj}} \tag{1}$$

m_i is the mass of the particle i, $\mathbf{x}_\mathrm{i}$ is the position vector for particle i and $\boldsymbol{g}$ is the gravitational acceleration vector. $\mathbf{F_{nj}}$ and $\mathbf{F_{nj}}$ are the contact force vectors applied by particle j in the normal and tangential directions. In this equation, all contact forces acting on particle i are calculated and summed up.

The interaction forces between a snow particles and the modelled snowboard are calculated with the above method, and they are also calculated using the Voigt model.

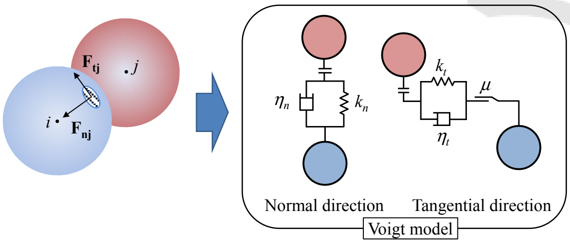

Figure 1: Snow modelling with particle element method.

2.2 Snowboard Model

A snowboard is considered to be a rigid body in the simulation. The motion of the snowboard is reproduced by numerically solving motion equations with six degrees of freedom, including translational and rotational motion. When the board contacts snow particles, the interaction force is determined by the method shown in the previous section and the calculated force is considered to be an external force acting the board.

3 SIMULATION CONDITIONS

3.1 Shape of Snowboard

Four snowboards were modelled to evaluate the influence of sidecut radius. The sidecut radii of the models are 15 m (R15), 10 m (R10) and 5 m (R5). A board without a sidecut was also modelled. The modelled boards are illustrated in Figure 2. A coordinate system local to the board is located at the centre of each board. The x axis is set along the longitudinal direction of the board. The y axis points along the width of the board, and the z axis points in the vertical direction to the board. The board dimensions, mass and moment of inertia are shown in Table 1. To verify the effect of the sidecut geometry, the mass and moment of inertia the board are kept constant for all the modelled boards. Furthermore, to represent a rider simply and consistently, a concentrated mass of 60 kg is located at the centre of the board coordinate system.

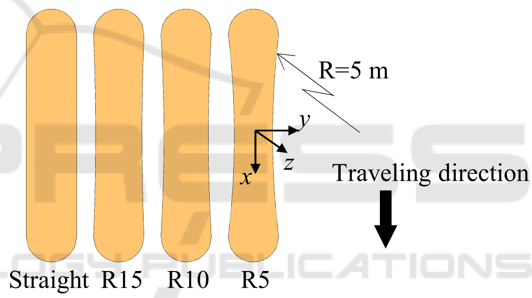

Figure 2: Geometry of the modelled snowboard.

Table 1: Board properties.

Length	Width	Mass	Inertia moment		
			I_{xx}	I_{yy}	I_{zz}
1.5 m	0.3 m	3.3 kg	0.02 kgm^2	0.62 kgm^2	0.65 kgm^2

3.2 Slope Condition

We set up a slope tilted at an angle of 10° in the simulated environment. Many particle elements cover the slope and reproduce granular snow with parameters modified from those used by Abe et al. (2011).

3.3 Initial Attitude and Load Torque

The initial Attitude of the board is rotated 10° about the y axis to be parallel to the slope and the x axis of the board coordinate system is parallel with the fall line of the slope. Then, the boards are given an initial velocity of 1 m/s in the x axis direction and slide down the slope.

During the whole simulation, a torque of −30 Nm is applied about the x axis to a board. Simultaneously, a 5 Nm torque is applied about the z axis for 0.4 s following the start of the run. In order to evaluate influence of the sidecut radius on turn behaviour, loading conditions to each board are matched.

4 RESULT AND DISCUSSION

Figure 3 shows the trajectories of each board's centre during the simulated run. In the global coordinate system, the X and Y axes are located on the horizontal plane, and the Z axis points in the vertical direction. The amount of movement in the Y direction is increased as the sidecut radius decreases. This is consistent with general theory about the manner in which snowboards behave. Although the trajectories of the straight board and the R15 board are similar, the R5 board turns considerably after torque is applied, consequently running off the side of the slope.

Figure 4 shows the forces acting on the board in the Y direction from the slope. These forces are averaged over 0.1 s. The force in the Y direction increases as the sidecut radius decreases. Thus, the influence of sidecut radius appears in the reaction force supplied by the snow surface.

In addition, the attack angle, which is the angle formed by the travelling direction of the board and the x axis of the board coordinate system, is shown in Figure 5. These angles are averaged over 0.1 s. The reaction force from the slope acting in the direction opposite to the travelling direction increases the y axis force component because the attack angle increases (Figure 6). The y axis force component corresponds to the centripetal force on the board as it turns. However, as the attack angle increases further, the y axis force component (board coordinates system) increases, but the force in the global Y direction may decrease. In these conditions, the turn becomes a skid turn.

Comparing the attack angle between the different sidecut radii, the small sidecut radius increases the angle. Because this increases the reaction force in the y direction of the board coordinate system, the movement of the turn also increases as the result. However, by focusing on the variation of the force in time, it is observed that the attack angle decreases when the sidecut radius is R15 or more, and decreases when the sidecut radius is R10 or less. In the case of R10 or less, the attack angle tends to be large. However, the force in the y direction of the board R5 decreases because of the large attack angle when the attack angle is at the maximum (from 0.7s to 0.8s).

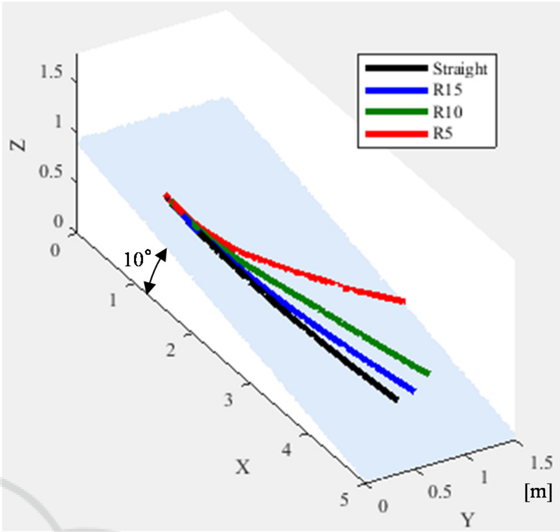

Figure 3: Board trajectories.

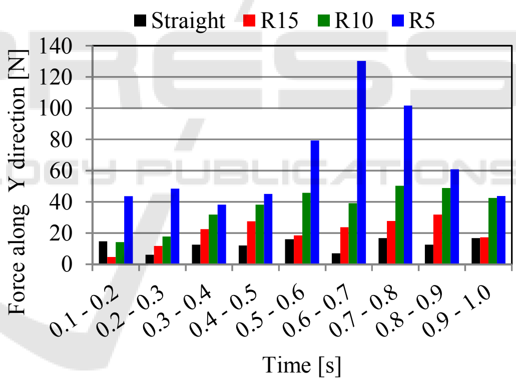

Figure 4: Reaction force acting on the board.

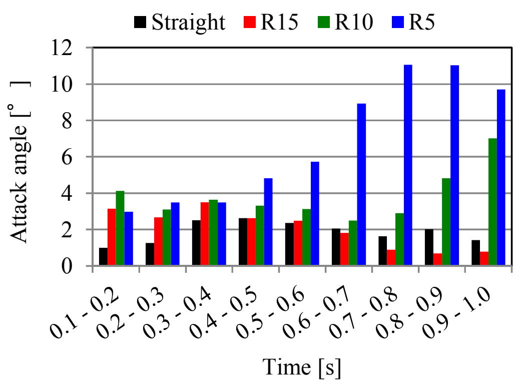

Figure 5: Influence of sidecut radius on attack angle.

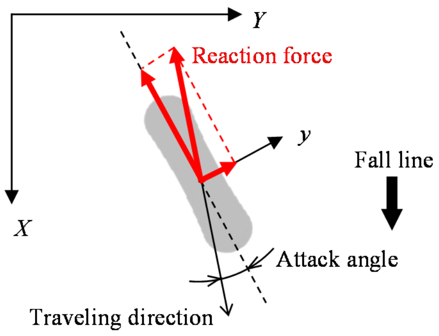

Figure 6: Attack angle.

5 CONCLUSIONS

A simulation model which represents snow surface with particle elements was developed to quantify snowboarding performance of prototypes. The model evaluated the turn characteristics of the modelled snowboards with different sidecuts and helps to understand their tendency. The particle element allows to evaluate the reaction force from the snow surface in detail. Moreover it was possible to understand the influence of the characteristics on the reaction force due to the shape and attitude of the board.

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