Kinesiologia Slovenica, 22, 3, 16–22 (2016), ISSN 1318-2269

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# MECHANICAL MODEL OF THE RELATIONSHIP BETWEEN THE BODY MASS OF SNOWBOARDERS AND TIME NEEDED TO DESCEND ON SLOPE

# MEHANSKI MODEL POVEZANOSTI MED TELESNO TEŽO IN HITROSTJO DRSENJA PRI DESKAJU NA SNEGU

## ABSTRACT

Paper is based on mechanical modeling in snowboarding. Snowboarder's mass is not prescribed by rules so aim of study was to examine the impact of snowboarder's mass (together with equipment) on time needed to descent 400 m straight down the slope. Model was developed respecting forces that acting on snowboarder during descent. Some forces was excluded due to complexity as well as turning during descend. Computer simulation showed that mass have influence on descend time (lower mass – longer time). Future studies should take more parameters into calculation to get close to realistic conditions on track.

*Key words:* computer simulation, forces, predict outcome, biomechanics

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## IZVLEČEK

Članek obravnava mehaniko modeliranja na področju deskanja na snegu. Teža deskarja na snegu ni predpisana s pravili, zato je bil naš cilj preučiti vpliv telesne teže deskarja (skupaj z opremo) na hitrost drsenja naravnost po 400 m dolgem pobočju. Predstavljeni model upošteva sile, ki na deskarja delujejo med spustom naravnost, zaradi kompleksnosti pa niso bilo upoštevane sile, do katerih prihaja ob odstopanjih smeri drsenja. Računalniška simulacija je pokazala, da telesna teža deskarja vpliva na nižji doseženi čas drsenja naravnost po pobočju (manjša teža-daljši čas). Pri nadaljnjih študijah bi bilo potrebno upoštevati še več parametrov, kar bi prispevalo k boljši oceni realnosti pogojev na progi.

*Ključne besede:* računalniške simulacije, sile, predvidevanje rezultatov, biomehanika

## INTRODUCTION

The role of simulation models in sport disciplines has become relevant lately due to the multiple advantages that they may offer sports teams, coaches and practitioners (Bruzzo at al. 2016). Motion simulation can help sports training, sports science analysis methods to achieve experiential training methods from stylized transition, leading to faster and more effectively improve the level of sports training and athletic performance (Yang, 2016). Physical or mechanical modeling is usually followed by computer simulation and even visualization to interpret and understand data easier. Modeling and simulation in sports is commonly used in situations where it is necessary to predict or calculate the outcome of an activity by changing the input parameters of the model without the need for actual practice of this activity. It is almost impossible, due the complexity of implementation, to ask (for example) shot putter to throw a shot identical several times in a row, varying only the angle of release to determine the influence of the angle on the length of throws. On the other hand, the computer simulation of mechanical model of the shot put will give, in a really short time, a large number of throw lengths for equal number of different angles. In modeling, the more input parameters taken into account will give the greater reliability of the model. Later, the reliability of a simulation depends on the accuracy of the models used in the simulation (Kawai, Yamaguchi and Sakata, 2004). Mechanical models used in the study of sports activities (which include the model developed in this paper) are based on the fact that such kind of movement must take place by Newton's laws of motion. So Bezodis, Trewartha and Salo (2015) used a computer simulation to study sprint acceleration, Begon, Colloud and Sardain (2010) to study kayaking, Rausavljević, Spasić and Jošt (2012) to study ski jumping, King, Yeadon and Kong (2008) to study the takeoff phase in vaulting, tumbling and springboard diving, Gerritsen, vandenBogert and Nachbauer (1997) to investigate ACL injuries during landing movements in downhill skiing, Bruzzo at al. (2016) to study cross-country skiing,… Chen and Qi (2009) developed a two dimensional model to simulate skiing movements based on multibody system. The results showed that the model can simulate simple types of skiing, and can provide kinematic and kinetic data such as the skier's displacement, velocity, acceleration, joint moment and force, and ground reaction force.

To the best of our knowledge no study up to date examined the problem of biomechanical modeling in snowboarding. There are several most important explanations. First, compared with skiing, snowboarding is a relatively young sport, so less number of research and scientific publications on snowboard not surprising. Many physical forces have an impact on snowboarder during descending but in this study developed mechanical model is simplified to show how mass of snowboarder affect time needed to descend straight downhill without turning. Why mass? Since the mass of snowboarders is not prescribed by the rules and is relatively easy to change, the authors of this study believe that the impact of snowboarder's mass on some kinematic parameters of snowboarding was interesting to explore, since such research (by the knowledge of the authors of this study) are not published yet. Knowing the laws of physics, specifically mechanics, it is evident that the greater mass of snowboarder will help him in some way but not in the other. Because of that indeterminate relation, mechanical model used in this study was developed, to determine whether the snowboarder gets benefits because of the greater mass or not. In all snowboard disciplines, except those in which points are scored for amplitude, originality and quality of tricks (slopestyle, halfpipe and big air), finishing the race in less time than opponent means a better result.

The main purpose of this study was to examine the influence of a snowboarder's mass on the time needed to descend 400 m regardless of whether the values of other parameters used in the mechanics model are constant. Track length of 400 m is taken into calculation because most snowboard disciplines in which time is important (slalom, giant slalom, parallel slalom, parallel giant slalom) can be, according to the rules (USSA Snowboarding competition guide , 2016), organized on the tracks of that length (only for snowboardcross minimum length is 500 m). The weight of snowboarder includes the mass of athletes along with the equipment (clothing, footwear, snowboard, protection,...).

## MATERIALS AND METHODS

Mechanical model on Figure 1 shows forces and the components of forces acting on the snowboarder during the translational descend a slope. It may be noted that the buoyancy force ignored because its small amount due to the low air density and the fact that it will at all times act in the same amount on snowboarder and equipment against the force of gravity, reducing it by a certain amount. It is logical to assume that the snowboarder, because of unsymmetrical position of his body during the descent, is exposed to aerodynamic force too but that force is neglected due to the complexity of developing such a model. From same reason, the snowboarder and equipment are assumed to be a system of rigid bodies that won't deform under any kind of force.

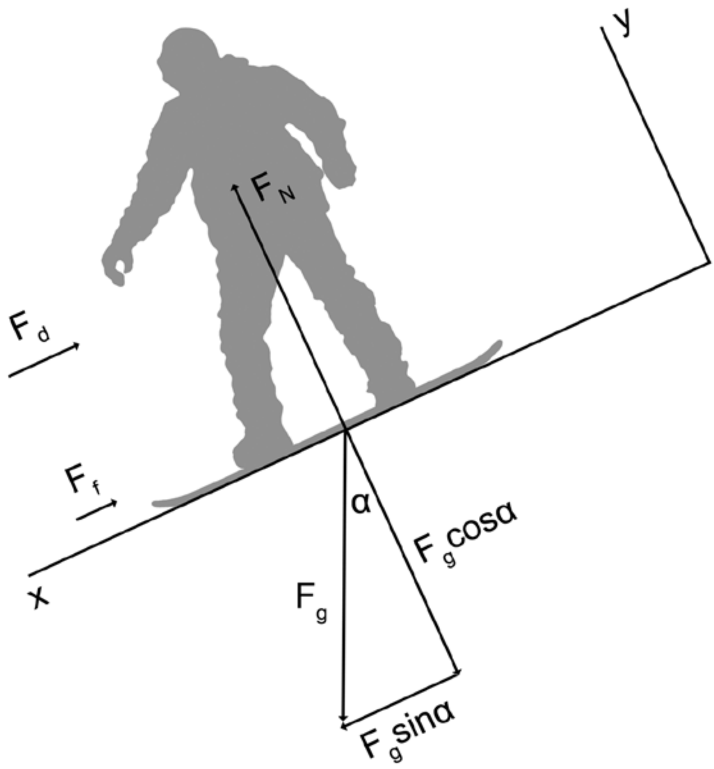


Figure 1. Forces acting on snowboarder during descending ($F_g$-force of gravity, $F_N$-normal force, $F_D$-drag force, $F_f$ –friction force, α-slope angle, x & y-axis)

**Model development**

Figure 1 shows that the sum of forces by the coordinate y axis (the axis perpendicular to the slope) is zero because the component of the gravitational force perpendicular to the slope ($F_g\cos\alpha$) have equal amount but opposite direction of the normal force:

$$\Sigma F_y=F_g\cos\alpha+(-F_N)=0$$

Therefore there is no movement around the y axis. On the other hand, to get the resultant force that will "push" snowboarder down the slope, it is necessary to sum all the remaining forces acting on him. The sum of forces by the coordinate x axis (the axis parallel to the slope) is as follows:

$$F=F_g\sin\alpha-F_f-F_D$$

If we take that:

$$F_f=\mu_k F_N$$

$$F_N=F_g\cos\alpha,$$

$$F_g=mg$$

$$F_D=½\rho CAv^2$$

(where, $\mu_k$-kinetic friction coefficient between snow and snowboard, g-acceleration of gravity force, ρ-air density, C-drag coefficient, A-frontal area of snowboarder and equipment perpendicular to velocity vector, v-velocity of snowboarder) the same expression can be written as:

$$F=mg\sin\alpha-\mu_k mg\cos\alpha-½\rho CAv^2$$

If we know that F=ma (where a-acceleration) and divide the resulting expression by the mass we get the acceleration of snowboarder at any given moment:

$$a= g\sin\alpha- \mu_k g\cos\alpha-\rho CAv^2/2m$$

Now when we have acceleration we can calculate snowboarder's displacement (Δr) based on:

$$\Delta r=r_i+v_i t+½at^2$$

(where $r_i$-initial position of snowboarder, $v_i$-initial velocity of snowboarder and t-time interval) for any desired time interval t. Snowboarder's velocity on the end of chosen time interval (v) will be:

$$v^2=2a\Delta r+ v_i^2$$

After modeling is completed and all expressions are written the computer simulation of the mechanical model was written in the Borland C++ computer programming environment.

To study the effect of only a single parameter, in this case the mass, other parameters are taken in the calculations as immutable. Vernillo, Pisoni and Thiébat (2016) reported 77.2 kg as average mass of elite snowboarders and we decided to use that mass as reference for modeling so snowboarder's mass in the simulation procedure varied between 67.2 kg and 87.2 kg (±10 kg). Average angle of slope incline used as input parameter for this model was 17.5 degree which is calculated (using Pythagorean theorem) on that way that in combination with previously mentioned 400 m length can meet requirements of vertical drop determined by rules for all "time measuring" snowboard disciplines (slalom, giant slalom, parallel slalom, parallel giant slalom and snowboardcross) so vertical drop is 120 m (between minimum 80 m for parallel slalom and maximum 240 m for snowboardcross). Different variables, such as temperature, the type of ice crystals in the snowpack, the type of wax on the running surface of the ski, and the skier's velocity, dominate the friction process under different conditions (Lind and Sanders, 2004). Hasler, Schindelwig, Knoflach, Reichl and Nachbauer (2014) reported that friction coefficients varied between 0.024 and 0.042 for different snowboard base structures and waxes and concluded that for modeling the speed dependency of friction on snow, a realistic estimation of the effective contact area as well as water film distribution and thickness would be necessary. Because of that, authors of this study have agreed to use constant kinetic friction coefficients of 0.033 in this mechanical model. As kinetic friction coefficients of 0.033 was used based on study by Hasler et al. (2014), the same air temperature of -6°C was used in this modeling so air density of 1.321 kg/m$^3$ was calculated (ρ=p/RT where p-absolute pressure of 101.325 kPa, R-specific gas constant of 287.058 J/kgK and T-absolute temperature of 267.15 K). Frontal area of snowboarder is used as constant and perpendicular to slope during descend. To calculate frontal area, frontal picture of snowboarder (in upright position) and equipment was taken. Area of 0.725 m$^2$ was later calculated using Photoshop CS4 computer raster graphics editing software (version 11.0). McIlveen (2002) wrote that drag coefficient must be found by experiment for all realistically complex bodies and flows and uses value of 0.6 as rough estimate for the human form. Same year, Zatsiorsky (2002) reported data for drag coefficients of 239 males and 92 females measured in wind tunnel (Penwarden, Grigg and Rayment 1978). Drag coefficients ranged from 1.05 to 1.11 for people standing sideways to the wind (speed 5 to 8.3 m/s). Authors of this study decided to use drag coefficient of 1.11 as constant in calculations because snowboarder will move at speeds higher than 8.3 m/s most of the time during descend (8.3 m/s snowboarder reach about 3 seconds from start judging by the results of simulation). Constant of 9.81 m/s$^2$ was used as acceleration of gravity force. Apart from the snowboarder's mass, all mentioned input parameters are held constant and have the purpose of calculating the snowboarder's displacement and position every 0.001 second.

## RESULTS

Computer simulation was used to calculate 21 time results depending on input mass change. The simulation started by inputting the initial jumper's mass value of 67.2 kg. Results shown in table 1 show 10 times for every mass decrease by 1 kg (from average mass of 77.2 kg), time for average mass and 10 times for every mass increase by 1 kg.

Table 1. Different times for different mass values on 400 m straight slope; m-mass (kg), t-time (s)

| m | t | m | t | m | t | m | t | m | t |
|---|---|---|---|---|---|---|---|---|---|
| 67.2 | 26.682 | 72.2 | 26.084 | | | 78.2 | 25.457 | 83.2 | 24.997 |
| 68.2 | 26.556 | 73.2 | 25.973 | | | 79.2 | 25.361 | 84.2 | 24.911 |
| 69.2 | 26.434 | 74.2 | 25.865 | 77.2 | 25.555 | 80.2 | 25.267 | 85.2 | 24.827 |
| 70.2 | 26.314 | 75.2 | 25.759 | | | 81.2 | 25.175 | 86.2 | 24.744 |
| 71.2 | 26.198 | 76.2 | 25.656 | | | 82.2 | 25.085 | 87.2 | 24.664 |

Times in table 1 confirmed that mass negatively affect on time snowboarder need to descend. 10 kg lighter snowboarder will have 1.127 s longer running time on 400 m straight slope compared with snowboarder of 77.2 kg. On the other hand, snowboarder of 77.2 kg will have 0.891 s longer running time on 400 m straight slope compared with snowboarder of 87.2 kg. By this example, it is obvious that greater mass reduces time by significant amount because time in snowboarding is measured in hundredths of a second.

## DISCUSSION AND CONCLUSIONS

The main finding of this study is that mass of snowboarder have influence on time needed to straight descend over 400 m track. Greater mass of snowboarder reduces the time for translational kind of movement described with this model regarding used input parameters.

The athlete must usually work against gravity but in downhill skiing, friction and drag affect the skier most because the skier is not working against gravity (Abell and Braselton 2009). The same thing goes for snowboarding. It is logical that greater mass of snowboarder increases normal force resulting higher friction force which will reduce snowboarder's velocity but higher mass in the same time produces higher amount of force of gravity causing higher $F_g \sin\alpha$ component that "pushing" snowboarder downhill. It is also logical that higher mass will increase snowboarder's volume resulting snowboarder's perpendicular area to increase. Increasing in $F_g \sin\alpha$ and A due to mass are not proportional because gaining mass will produce volume growing in three dimensions and drag force will have influence only on two dimensional area perpendicular to velocity vector, so A will increases slower than (useful) $F_g \sin\alpha$. That is the main reason why greater mass suppose to be benefit for snowboarders. Despite that, question is what is composition of gained mass and how one can use it in his/her advantage, but that is not question to discuss in any relation to mechanical model developed in this study. We can only assume that for snowboarder greater muscle mass can be more useful than fat tissue because greater muscle mass often assume availability of greater muscle force snowboarder can produce and use to deal with outer forces (if that extra muscle mass is well distributed in the right places for that particular discipline so snowboarder can take advantage of it at all). To meet the demands of snowboarding competition, elite snowboarders require highly developed muscular strength and power (Vernillo et al. 2016) which can be achieved by gaining muscle mass.

### Study limitations

The biggest limiting factor is lack of information that can only be collected using the wind tunnel. Regardless technique, precise drag coefficient for a particular body position and type of material of which equipment will be manufactured are essential for this kind of activity where time is measured in hundredths of a second. The thickness of the water film between the snow and snowboard will also play important role in amount of friction coefficient, as well as changes in speed and snow temperatures at different parts of track. Study is also limited by fact that buoyancy force is eliminated from model in start due to small amount and constant direction; despite the changing altitude during descend which have influence on air density and amount of buoyancy force.

In future studies that will investigate relations of mass and time (and/or speed) in translational snowboarding movement, more input parameters should be used in consideration such as aerodynamic force, changing of friction coefficient under speed change and drag friction.

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