Bulletin of the JSME
Vol.8, No.5, 2021
Mechanical Engineering Journal

Simulation study to elucidate the mechanism of ollie jump in skateboarding

Motomu NAKASHIMA* and Yohei CHIDA*
*School of Engineering, Tokyo Institute of Technology
2-12-2 Ookayama, Meguro-ku, Tokyo 152-8552, Japan
E-mail: motomu@sc.e.titech.ac.jp

Received 21 June 2021; Revised: 5 August 2021; Accepted: 17 August 2021

Abstract
In skateboarding as a sports event, the riders compete in difficulty and completeness of acrobatic motions called "tricks". As a basic trick, Ollie is performed popularly. However, the basic mechanical principle of the Ollie has not been discussed to date, especially for the Ollie jump (the jumping phase of Ollie). The objective of this study was to elucidate the mechanism of Ollie jump in skateboarding. A simulation model was firstly constructed on a multibody dynamics analysis platform. Next, an experiment using an actual rider was conducted to acquire the motion of the feet during the Ollie jump. By inputting the acquired motion of the feet into the model, a simulation of Ollie jump was carried out. In addition, a parameter study with respect to the geometry of the skateboard and the motion of the rider's feet was conducted. It was found that the simulated Ollie jump was successful since the skateboard reached a sufficient height and became sufficiently horizontal at the peak height. It was also found that the Ollie jump can be divided into five stages from the mechanical point of view. From the parameter study, it was found that large kick angle of the deck or large distance between two trucks of the deck might cause difficulty in the contact of the tail and the ground, while small kick angle or small distance between two trucks might result in excessive rotating angle of the deck. In addition, three important points for a successful Ollie jump were found to be, to produce sufficiently fast rotational movement of the skateboard around the rear wheels, to separate both feet from the deck before the tail of the deck hits the ground, and to separate the rear foot from the deck at the final stage.

Keywords : Skateboard, Ollie, Sports engineering, Multibody dynamics, Modeling, Simulation

1. Introduction

Skateboarding is becoming so popular that it was certified as an Olympic sports event recently. In skateboarding as a sports event, the riders compete in difficulty and completeness of acrobatic motions called "tricks." As a basic trick, "Ollie" is performed popularly. In the Ollie, the rider kicks down the tail of the skateboard hard, simultaneously jumps up, and controls the skateboard in the air. This sequence of the trick is considered to be realized by an appropriate mechanical interaction between the rider, the skateboard, and the ground.

There were several previous studies of skateboarding from the mechanical viewpoint. As a pioneering work, Hubbard (1979) derived the lateral equations of motion of a skateboard and presented its stability criteria. Hubbard (1980) further presented a model for the dynamics of a skateboard and rider in a simple tracking task. Ispolov and Smolnikov (1996) considered the dynamics of the controlled motion of a skateboard over a horizontal plane, in which a rider provided the propulsion force and controlled the skateboard by reaction forces of non-holonomic constraints. Kuleshov (2006) as well as Kremnev and Kuleshov (2008) constructed a simple mathematical model describing the motion of the rider on the skateboard in the form of Gibbs-Appell equations, and conducted a stability analysis of the propelling motion of the skateboard. Varszegi et al. (2014) incorporated reflex time delay into their mechanical model of the rider-skateboard system, and showed that reflex delay influenced the stability of the skateboard's motion.

All above-mentioned studies focused on the horizontal movement (cruising) of the skateboard. For tricks such as the

Paper No.21-00230
J-STAGE Advance Publication date : 3 September, 2021
[DOI: 10.1299/mej.21-00230]

Ollie, few studies have been conducted. Determan et al. (2006) simply measured the ground reaction force during the kickflip, which is similar to the Ollie but differs slightly as it incorporates a kicking or flicking motion of the foot during the airborne phase of the jumping movement that causes the skateboard to rotate in the air about its longitudinal axis underneath the rider's feet. Vorlicek et al. (2015) investigated the muscle activity for the lower limb of riders in the Ollie. Adi et al. (2010) developed a three-dimensional simulation system of angle rotations to effectively learn skateboarding.

Despite all of the above-mentioned previous studies, the mechanical principle of the Ollie has not been discussed to date. In particular, a skateboard moves together with the rider in the jumping phase of Ollie (hereinafter, this phase is called "Ollie jump") even though the skateboard is not connected to the rider's feet. It is a completely different phenomenon from the jump in snowboarding, in which the snowboard is connected to the rider's feet. In other words, even though the rider only kicks the skateboard downward, the skateboard moves upward. Indeed, this is an interesting physical phenomenon. One key issue in the Ollie jump is that the tail of the skateboard hits the ground due to kicking by the rider. This hitting is intentionally done by the rider. Therefore, it is considered that the downward kicking by the rider is transformed into the upward jumping of the skateboard through the hitting phase. However, detailed investigation for this phenomenon has not been conducted to date. If the mechanical principle of the Ollie jump is elucidated, it will be useful for riders to learn and teach the Ollie jump more effectively, also for manufacturers to develop new skateboards suitable for tricks.

The objective of this study was to elucidate the mechanism of Ollie jump in skateboarding. As the method to elucidate, physical simulation was employed in the present study. This was because any physical quantities to understand the phenomenon easily could be seen in a simulation, compared to an experiment in which physical quantities sometimes were difficult to measure accurately. For this purpose, an appropriate simulation model based on the laws of physics to represent the Ollie jump had to be constructed. Therefore, in this study, the simulation model was firstly constructed on a multibody dynamics analysis platform. Next, an experiment using an actual rider was conducted to acquire the motion of the feet during the Ollie jump. By inputting the acquired motion of the feet into the model, a simulation of Ollie jump was carried out. In addition, a parameter study with respect to the geometry of the skateboard and the motion of the rider's feet was conducted. The ground reaction force as well as the force between the rider's feet and the skateboard were investigated and the mechanical principle of the Ollie jump was discussed.

2. Methods

2.1 Simulation model

The simulation model in the present study was constructed using a commercial solver SIMPACK (Simpack2017, Dassault Systèmes, France) to conduct multi-body dynamics analysis. The skateboard model is shown in Fig. 1(a). Generally, there are three types of skateboard; 1) street board, 2) long skateboard, and 3) the mini cruiser. Since most tricks are performed using a street board, the street board (Fig. 1(b)) was used for the present study. All the dimensions of the model shown in Fig. 1(a) were determined based on those of the actual one shown in Fig. 1(b). A skateboard generally consists of three parts; 1) deck, 2) two trucks (one on each side of the front and rear), and 3) four wheels (two on each side of both the front and rear). A deck is a wooden plate on which a rider puts his/her feet. Both sides of a deck are gently warped up, which are utilized for tricks. The deck part of the simulation model is shown in Fig. 1(c) and Fig. 1(d). The deck part in the model was constructed by connecting rectangular and semicircular plates. Trucks are metallic parts (shown in Fig. 1(e)), which connect the deck and wheels. Usually trucks are used to change the propelling direction. Since such function was not necessary in the present study, the truck parts in the model were simplified, consisting of columns and rectangular prism, as shown in Fig. 1(f). Four wheels were modeled as short columns and connected to the trucks with one degree-of-freedom, that is, rotation about the axis. A slight rolling friction was defined between the wheels and trucks, based on the information of actual bearings used in the skateboard. For the rider, only the feet were modeled as two ellipsoids.

With respect to the forces between the ground and the wheels, contact force and friction force were defined. The contact force was represented as a force due to a virtual spring and damper, while the friction force was given as the Coulomb's friction, whose coefficient was set to 0.1. The force between the ground and the deck was also defined as the same as the force between the ground and the wheels, although the friction coefficient was set to 0.6 in this case. In addition, the forces between the deck and the rider's feet was also defined. The contact force was given as the virtual spring and damper force as the same as the other forces. The friction force, however, was given as the stick-slip force,

[DOI: 10.1299/mej.21-00230]

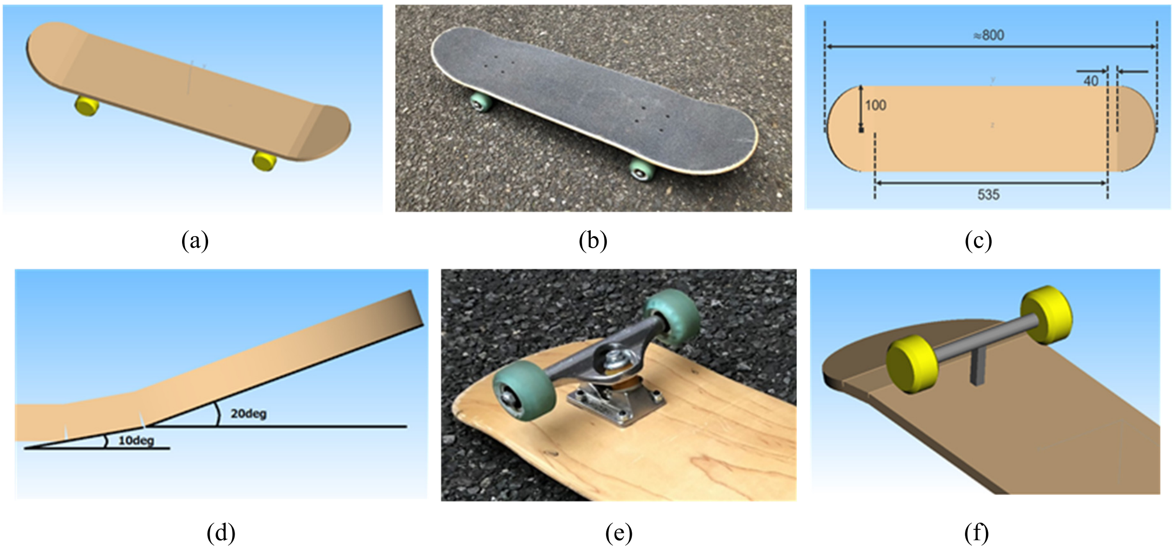

Fig. 1 Simulation model of a skateboard. (a) Overview, (b) an actual skateboard whose dimensions were put into the model, (c) dimensions of deck, (d) side angles of deck, (e) truck of an actual skateboard, (f) simplified truck in the model.

which had both static and dynamic frictions. The friction coefficients for the static (stick) and dynamic (slip) conditions were set to 1 and 0.8, respectively. The reason why the static and dynamic friction coefficients were used for the forces between the deck and the rider's feet was that the deck and feet were considered to be in the stick condition before the jump, and in the slip condition during the jump as a contact with relative velocity. On the other hand, the reason why the only one friction coefficient as a simpler setting was used for the forces between the ground and wheels as well as the force between the ground and deck was that the stick-slip phenomenon was not considered to play an important role in those forces.

2.2 Experiment to acquire foot motion

As an input to the simulation model, a rider's foot motion was acquired by an experiment. A rider (male, height 1.80 m, weight 65 kg, age 21) participated in this experiment. The rider had been skateboarding for two years and was recreational level. The experiment was approved by the Research Ethics Committee of the Tokyo Institute of Technology in advance, and written informed consent was obtained from the participant before the experiment. Eight infrared markers were attached to the skin around the first and fifth metatarsal bones as well as the inside and outside of the ankle joints for the right and left feet. The rider was asked to perform an Ollie on flat ground from a stationary state without propulsion. The motions of the markers on the feet were measured by a motion capture system with nine infrared cameras (MAC3D system, Motion Analysis Corporation, USA) at the frame rate of 250 frames per second. After sufficient time of practice, five successful trials were performed by the participant. Sufficient rest time was taken between the trials. As an example, a sequence of photographs of a trial is shown in Fig. 2.

The measured motions of the markers in a successful trial were put into the simulation model. For this purpose, eight virtual markers were defined on the feet in the model. The locations of the virtual markers corresponded to those of the actual markers. Each virtual marker was connected to a corresponding actual marker by a virtual spring and damper. Then, a preliminary simulation, in which the actual markers moved with the measured data, was conducted. In the simulation, the virtual markers on the feet as well as feet themselves were passively moved by the motions of the actual markers due to the virtual spring and damper forces. The foot motions, as the input for the main simulation, were obtained as the output of this preliminary simulation.

2.3 Analysis conditions

For simplicity, the movement of the skateboard was confined in a two-dimensional space, that is, x and z directions in the simulation. The x axis corresponds to the propulsive direction while the z axis corresponds to the vertical direction. The time step was 0.0001 s in the simulation. A simulation with the standard condition, in which all the above-mentioned

[DOI: 10.1299/mej.21-00230]

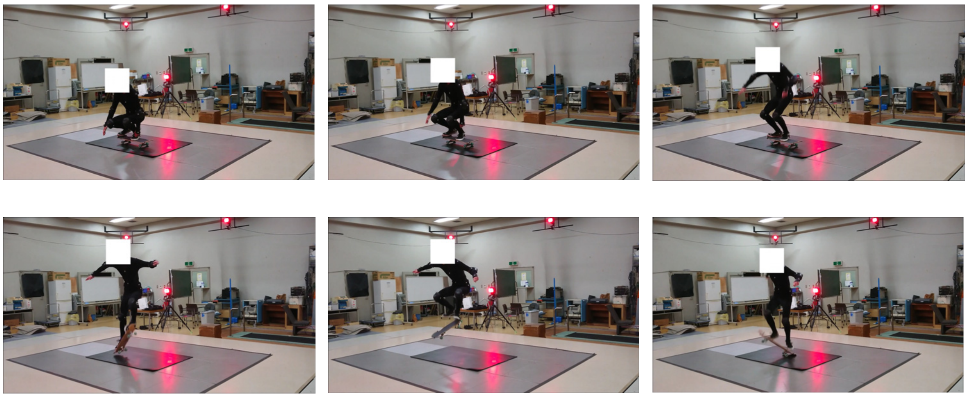

Fig. 2 A sequence of photographs of a Ollie jump. In the experiment, the rider was asked to perform an Ollie on flat ground from a stationary state without propulsion.

parameters were used, was carried out first. Secondly, a parameter study was conducted. In this parameter study, the kick angle (warping angle of the sides of the deck which is 20 degrees in Fig. 1(d)), the positions of trucks, the motion of the rear foot, and the motion of the front foot were changed respectively.

3. Results and discussion

3.1 Results of standard condition

The simulated motion of the Ollie jump is shown in Fig. 3. The vertical displacement of the center of mass and the absolute angle of the skateboard are shown in Fig. 4. As shown in Fig. 4(a), the maximum height of the skateboard reached 0.31 m at t = 0.24 s. In the previous study, the average jump height of the kickflip in the experiment was reported as 0.258 m (Determan et al., 2006). Since the maximum height in the present simulation exceeded this value, the Ollie jump in the present simulation could be considered as successful. With respect to the angle of the skateboard shown in Fig. 4(b), the angle was 0.50 radian (28.4 degrees) at the maximum height timing (t = 0.24 s). After that, the angle continued decreasing and became zero degrees (the skateboard became horizontal) at t = 0.37 s.

The ground reaction forces on the skateboard are shown in Fig. 5(a). The black, red, and blue lines are reaction forces on the front, rear wheels, and the tail, respectively. It was found that the front wheels had only a small peak around t = 0.03 s, while the rear wheels had a large value (724 N at t = 0.074 s) until t = 0.1 s. In addition, surprisingly, the tail had only a very small peak (6.9 N at t = 0.118 ~ 0.126 s). The tail hit the ground at this moment. However, there was no large sharp peak at this moment. This fact suggests that the leap of the skateboard is not realized by the reaction of the impact between the tail and ground.

The contact forces between the rider's feet and the deck of the skateboard are shown in Fig. 5(b). The black and red lines are contact forces between the rear and front feet, respectively. Initially, both feet supported the weight of the rider (t = 0 ~ 0.046 s). Then, from the jumping motion of the rider, first the front foot separated from the deck (t = 0.046 s) and a large force (557 N at t = 0.074 s) acted on the deck via the rear foot. After the rear foot separated from the deck (t = 0.095 s), the front foot contacts the deck three times (t = 0.126 ~ 0.127 s, 0.189 ~ 0.196 s, and 0.307 ~ 0.314 s). The impulses (the integrals of force over time) of these three contacts were calculated as 2.66, 0.19, and 0.92 Ns, respectively.

Based on these results, the schematic figure to explain the principle of the Ollie is shown in Fig. 6. The Ollie jump can be divided into five stages as follows:

1. The rider starts jumping (t = 0 ~ 0.046 s). Both feet contact the deck at this stage, as shown in Fig. 6(a).
2. The front foot separates from the deck while the rear foot pushes on the tail of the deck (t = 0.046 ~ 0.095 s). At this stage, the skateboard performs a rotational movement around the rear wheels, as shown in Fig. 6(b). From this rotational movement, the center of mass of the skateboard has an upward momentum.
3. The rear foot separates from the deck while the skateboard continues to perform the rotational movement around the rear wheels (t = 0.095 ~ 0.118 s), as shown in Fig. 6(c).
4. The tail of the deck contacts the ground and therefore the axis of the rotational movement is changed from the rear wheels into the tail (t = 0.118 ~ 0.126 s), as shown in Fig. 6(d). The skateboard still has an upward momentum at this stage.

[DOI: 10.1299/mej.21-00230]

Fig. 3 Simulated motion of Ollie jump. The skateboard rose up to 0.31 m height from the ground at t = 0.24 s. At that moment, the angle between the deck and the ground was 28.4 degrees.

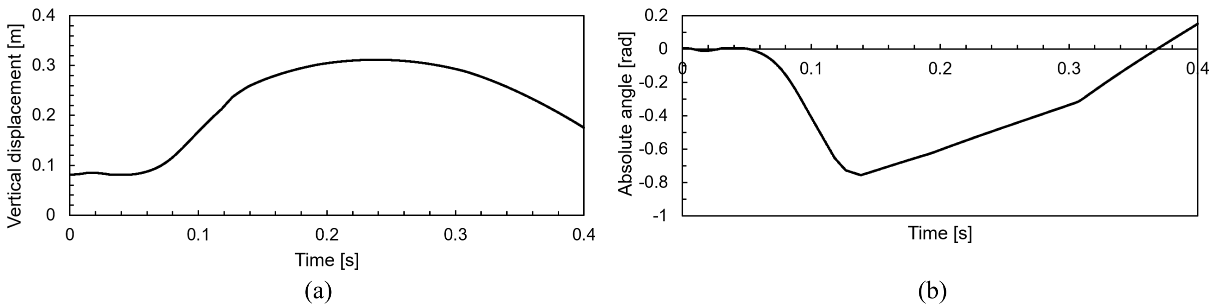

Fig. 4 Vertical displacement of the center of mass and absolute angle of the skateboard. (a) Vertical displacement of the center of mass for the skateboard, (b) absolute angle of the skateboard.

[DOI: 10.1299/mej.21-00230]

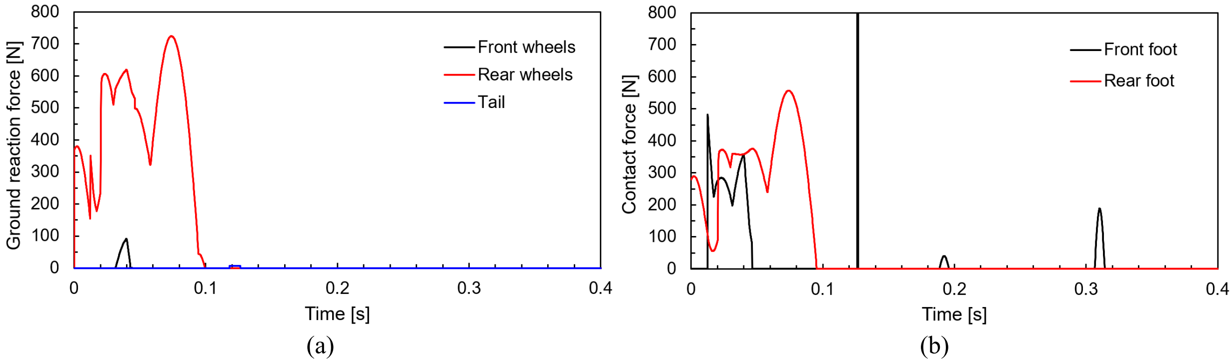

Fig. 5 Ground reaction forces on the skateboard and contact forces between the rider's feet and the deck of the skateboard. (a) Ground reaction forces on the skateboard, (b) contact forces between the rider's feet and the deck of the skateboard.

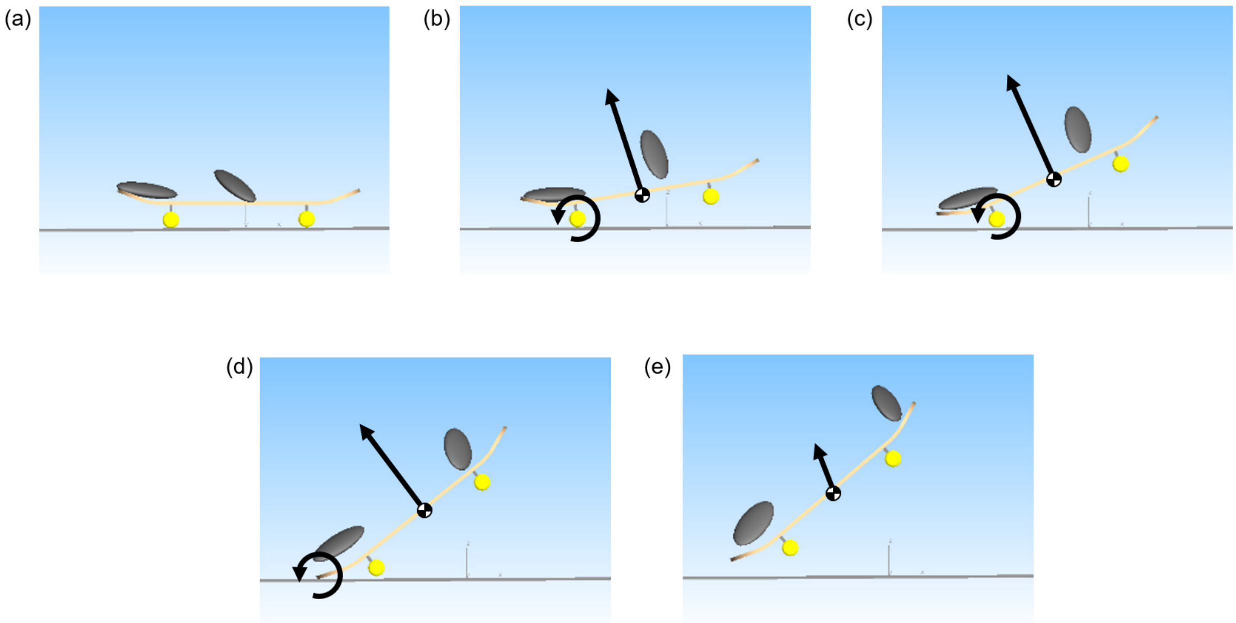

Fig. 6 Schematic figure to explain the principle of the Ollie jump. (a) Stage 1; The rider starts jumping. Both feet contact the deck. (b) Stage 2; The front foot separates from the deck while the rear foot pushes on the tail of the deck. The skateboard performs a rotational movement around the rear wheels. (c) Stage 3; The rear foot separates from the deck while the skateboard continues to perform the rotational movement around the rear wheels. (d) Stage 4; The tail of the deck contacts the ground and therefore the axis of the rotational movement is changed from the rear wheels into the tail. (e) Stage 5; The tail of the deck separates from the ground. The front foot contacts the deck several times.

5. The tail of the deck separates from the ground (t = 0.126 s ~). During this stage, the front foot contacts the deck several times. By these contacts, the rotational movement is canceled and the deck approaches the horizontal position, as shown in Fig. 6(e). The center of mass of the skateboard continues to go upward until the upward velocity becomes zero due to gravity as well as the downward impulse from contacts from the front foot.

3.2 Results of parameter study

3.2.1 Kick angle of the deck

The results of the parameter study for the kick angle of the deck are shown in Fig. 7. The kick angle of the standard condition was 20 degrees, as shown in Fig. 1(d). As the changed conditions, two cases of –2 degrees (18 degrees) and +2 degrees (22 degrees) were investigated. In Fig. 7(e), non-zero values mean that the tail of the deck contacts the ground at those moments. Therefore, from Fig. 7(e), it was found that the contact time (duration) between the ground and the tail

[DOI: 10.1299/mej.21-00230]

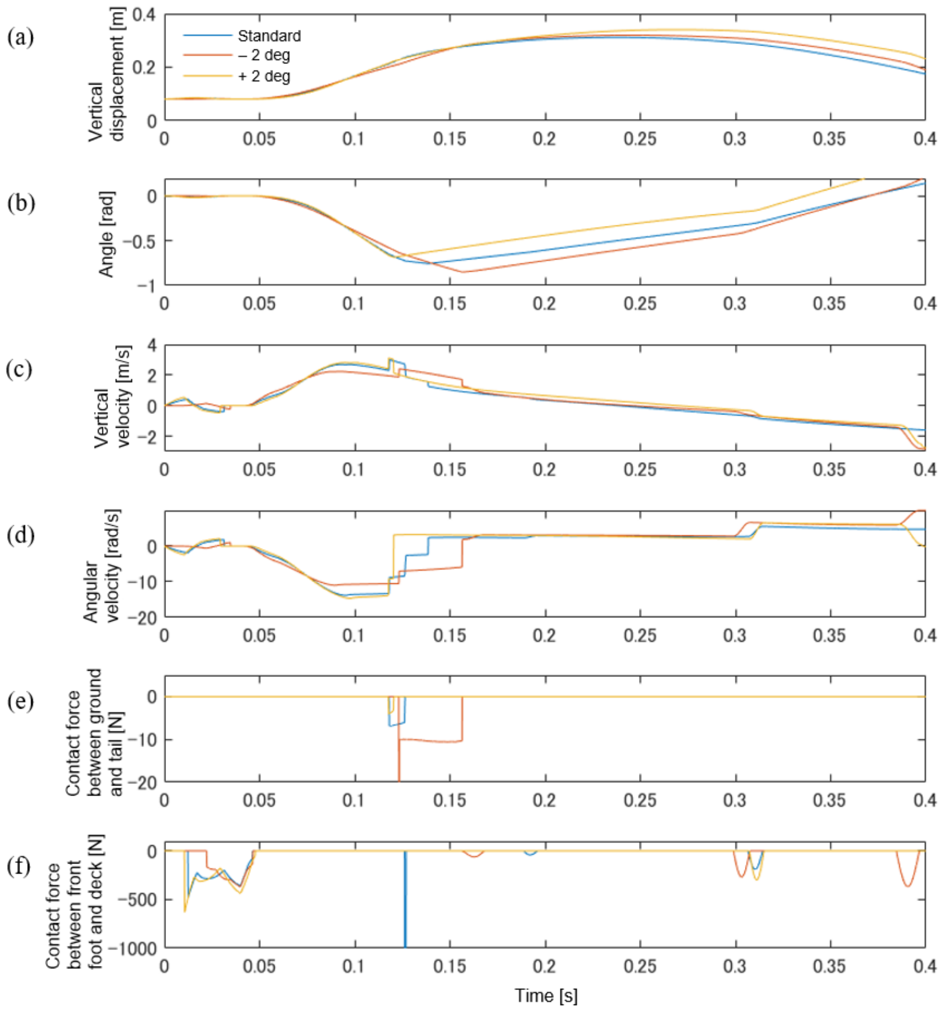

Fig. 7 Results of parameter study for the kick angle of the deck. The blue, orange and yellow lines represent the results of the standard condition, the case of -2 degrees, and the case of +2 degrees, respectively. (a) Vertical displacement of the center of mass of the skateboard, (b) absolute angle of the skateboard, (c) vertical velocity of the skateboard, (d) angular velocity of the skateboard, (e) contact force between ground and tail of the skateboard, (f) contact force between front foot and deck of the skateboard.

became shorter when the kick angle was large, while it became longer when the kick angle was small. In other words, the duration of Stage 4, which is described in Section 3.1, became shorter when the kick angle was large, while it became longer when the kick angle was small. As the results of this tendency, it was found that the maximum rotating angle of the deck shown in Fig. 7(b) became large when the kick angle was small. From these results, it can be said that too large a kick angle might cause difficulty in the contact of the tail and the ground, while too small a kick angle might result in excessive rotating angle of the deck in which the rider has to pull up the front foot rapidly and largely. It was difficult to draw any other clear tendency from this parameter study. For example, from Fig. 7(a), it was found that the maximum vertical displacement of the +2 degrees case was larger than that of the standard condition. This was because the vertical velocity of the +2 degrees case shown in Fig. 7(b) was larger than that of the standard condition at t = 0.10 ~ 0.115 s as well as t = 0.140 or later. However, the maximum vertical displacement of the –2 degrees case was also larger than that of the standard condition in Fig. 7(a), although the vertical velocity of the –2 degrees case was smaller than that of the standard condition at t = 0.10 ~ 0.115 s. This may be because the longer duration of Stage 4 (rotation around the tail) caused the larger vertical velocity, which is shown in Fig. 7(c) (t = 0.125 ~ 0.16 s), and because the vertical velocity in the standard condition was decreased by the sharp peak of the contact force from the front foot at t = 0.126 ~ 0.127 s, which is shown in Fig. 7(f). Therefore, it was difficult to draw any clear relationship between the kick angle and the maximum height of the Ollie jump.

[DOI: 10.1299/mej.21-00230]

3.2.2 Position of trucks

The results of the parameter study for the position of trucks are shown in Fig. 8. The position of trucks of the standard condition was 225 mm (the distance between one truck from the center of the deck). As the changed conditions, two cases of –5 mm (220 mm) and +5 degrees (230 mm) were investigated. In short, the results were found to be similar to those of the parameter study for the kick angle. For example, from Fig. 8(e), it was found that the contact time between the ground and the tail became shorter when the position of trucks was large, while it became longer when the position of trucks was small. The reason of this similar tendency is that the large position of trucks had a geometrical effect similar to that of the large kick angle at the moment when the tail of the deck started contacting the ground (the transition from Stage 3 to Stage 4). As the same as seen in the case of kick angle, it was difficult to draw any clear relationship between the position of trucks and the maximum height of the Ollie jump.

3.2.3 Motion of front foot

The results of parameter study for the motion of the front foot are shown in Figs. 9 and 10. In this parameter study, the vertical displacement of the front foot around t = 0.1 s was changed, since the front foot firstly contacted the deck during jumping at t = 0.126 s in the standard condition, which is shown in Fig. 5(b). Two conditions where the vertical displacement at t = 0.1 s was decreased for 10 mm (hereinafter –10 mm) and increased for 50 mm (hereinafter +50 mm) were investigated. In Fig. 9, the feet and deck of –10 mm are shown in red and those of +50 mm are shown in yellow. As

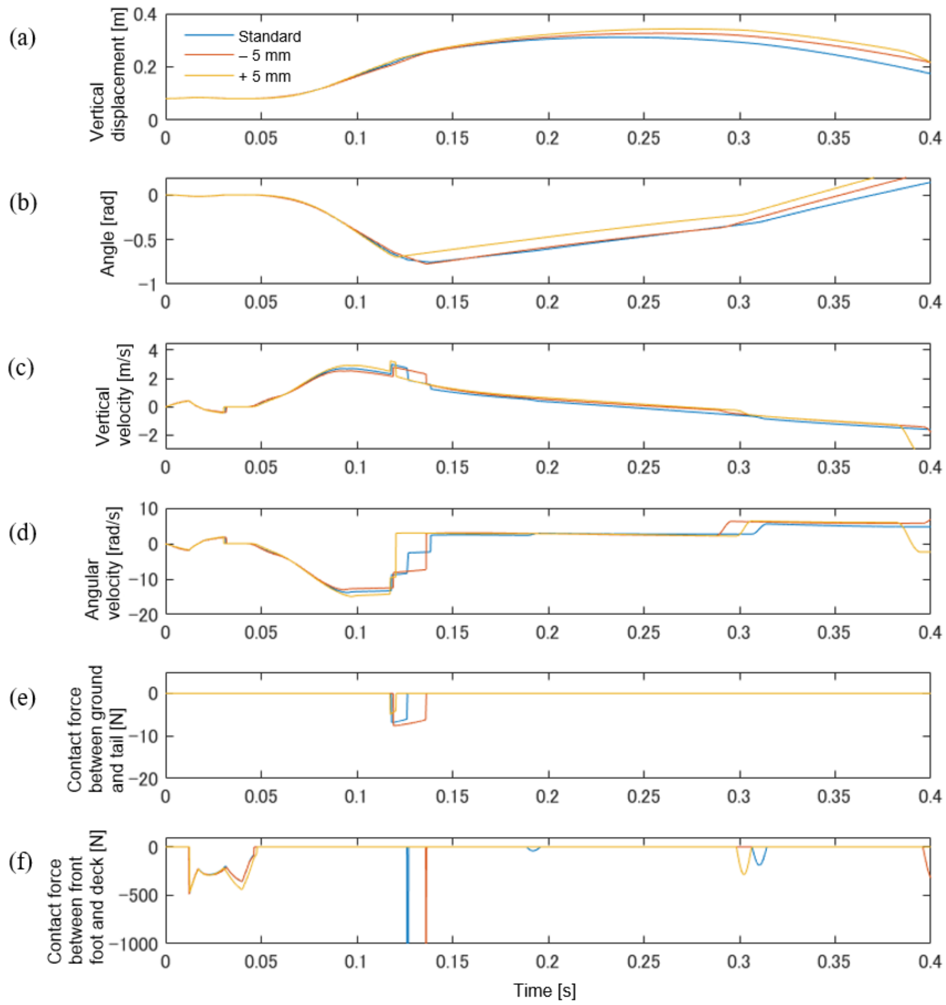

Fig. 8 Results of parameter study for the positions of trucks. The blue, orange and yellow lines represent the results of the standard condition, the case of -5 mm, and the case of +5 mm, respectively. (a) Vertical displacement of the center of mass of the skateboard, (b) absolute angle of the skateboard, (c) vertical velocity of the skateboard, (d) angular velocity of the skateboard, (e) contact force between ground and tail of the skateboard, (f) contact force between front foot and deck of the skateboard.

[DOI: 10.1299/mej.21-00230]

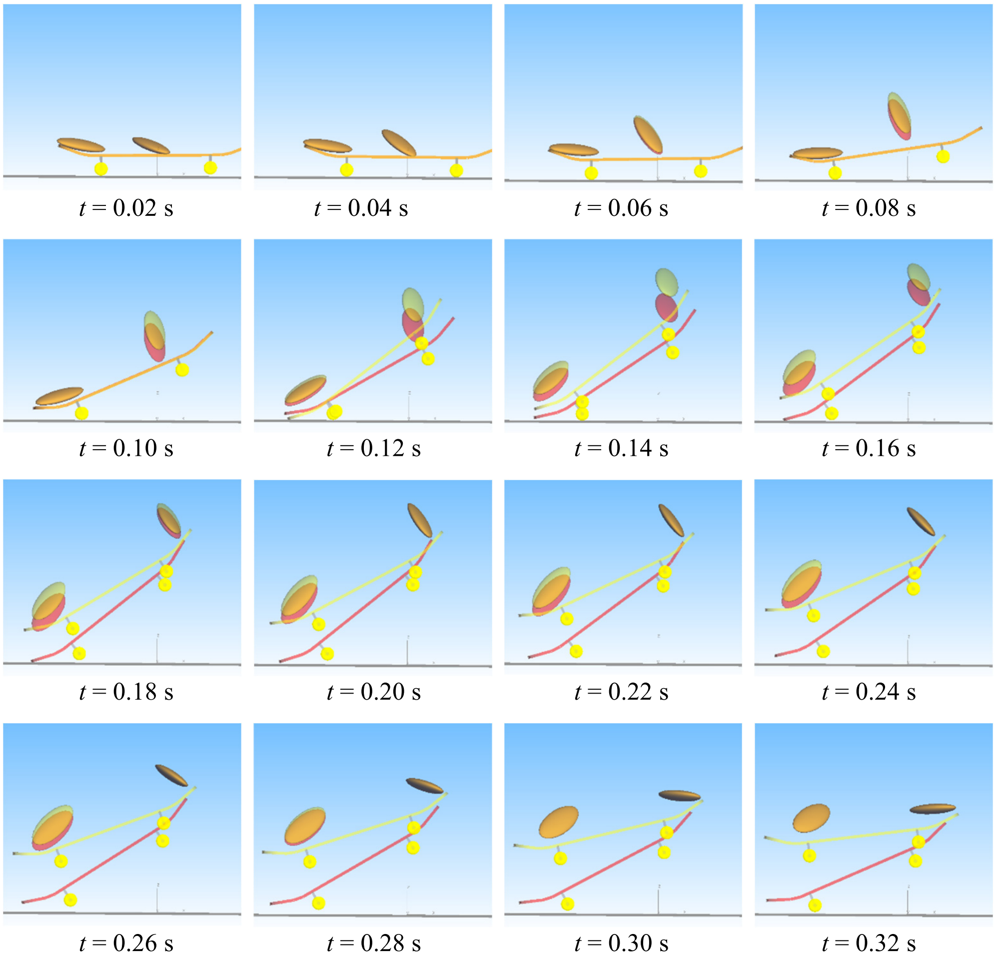

Fig. 9 Simulated motion of Ollie jump for the changed motions of the front foot. Two conditions where the vertical displacement at t = 0.1 s was decreased for 10 mm (hereinafter –10 mm) and increased for 50 mm (hereinafter +50 mm) were investigated. The feet and deck of –10 mm are shown in red and those of +50 mm are shown in yellow.

shown in the last screenshot of Fig. 9 (t = 0.32 s) as well as in Fig. 10(b), the skateboard became more horizontal in the case of +50 mm. This can be regarded as a better Ollie jump. Indeed, this jump looks like better than that in the standard condition, which is shown in Fig. 5, even though the vertical height of the center of mass of the deck was not so different, which is shown in Fig. 10(a). This may be because the rear foot was close to the deck due since the deck was more horizontal. This better jump was realized by the late first contact of the front foot to the deck at t = 0.135 s, whose sharp peak of the force is shown in Fig. 10(f). On the other hand, in the case of –10 mm, the vertical displacement of the skateboard was significantly low, as shown in Fig. 10(a). The absolute angle of the skateboard was also significantly higher as shown in Fig. 10(b), which means the skateboard did not became horizontal at the latter stage of the jump. This was induced by the early contact of the front foot to the deck at t = 0.112 s, which is shown in Fig. 10(f). Therefore, it can be concluded that it is important for the rider to pull up the front foot early and rapidly at the early stage of the Ollie jump.

3.2.4 Motion of rear foot

The most important role of the rear foot is to provide sufficient momentum to jump on the deck. In order to provide the momentum, sufficient impulse should be acted on the deck from the rear foot. A parameter study was conducted to investigate the sufficient amount of impulse. In this parameter study, the front foot was eliminated and the velocity of the rear foot was changed in the simulation. As a result, it was found that the impulse of 18.7 Ns was necessary to achieve the maximum height of 0.30 m for the center of mass of the skateboard.

Another important point for the rear foot is to move upward sufficiently fast so that the rear foot does not contact the deck after the tail of the deck separates from the ground (Stage 5 in Fig. 6). If the rear foot contacts the deck at that moment, it reduces the upward momentum of the deck significantly and therefore the jumping height would become very

[DOI: 10.1299/mej.21-00230]

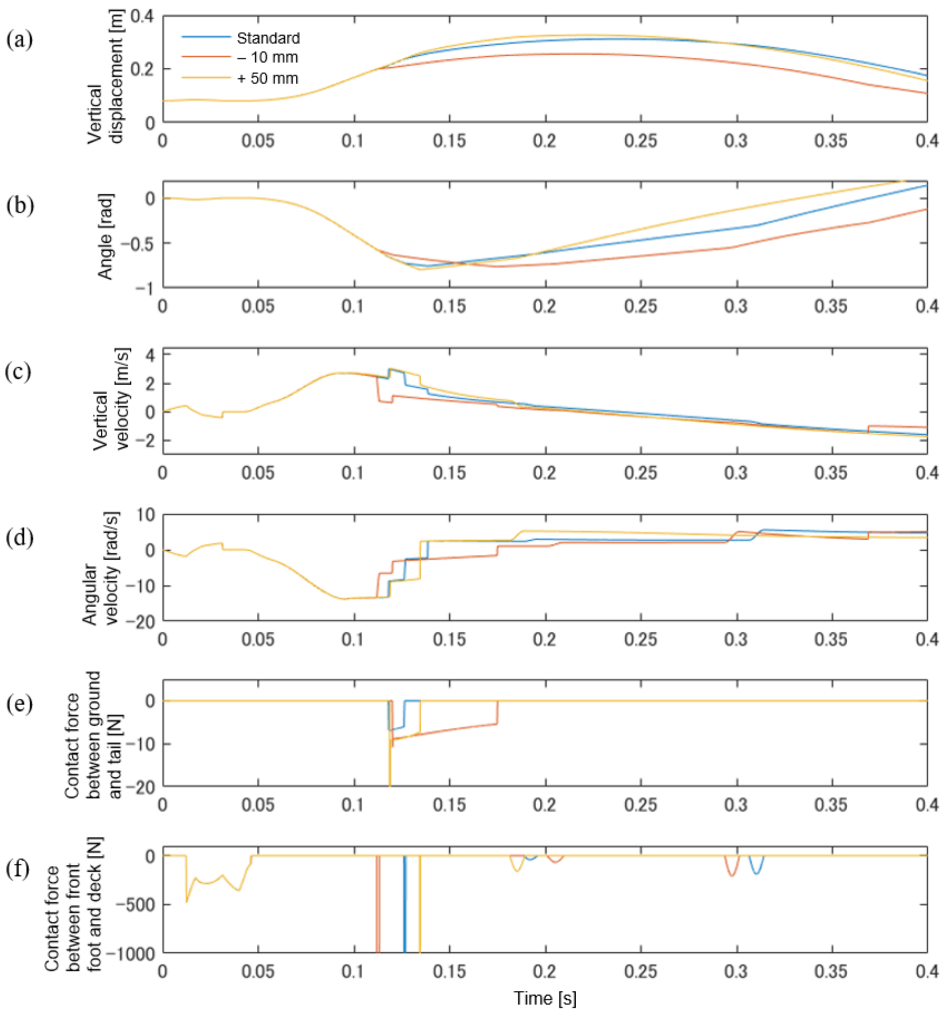

Fig. 10 Results of parameter study for the motion of the front foot. The blue, orange, and yellow lines represent the results of the standard condition, the case of –10 mm, and the case of +50 mm, respectively. (a) Vertical displacement of the center of mass of the skateboard, (b) absolute angle of the skateboard, (c) vertical velocity of the skateboard, (d) angular velocity of the skateboard, (e) contact force between ground and tail of the skateboard, (f) contact force between front foot and deck of the skateboard.

low. From another parameter study, in which the upward velocity of the rear foot after separating from the deck was changed, it was found that the rear foot must move upward more than 2.22 m/s.

It should be noted that the above values of 18.7 Ns and 2.22 m/s were merely examples in the situation of the present study. Those values will change due to the rider's height, body weight, and technique as well as the deck's dimension and structure.

3.3 Important points to accomplish a successful Ollie jump

Based on the above discussion, important points to accomplish a successful Ollie jump are summarized as follows:

1. At Stages 1 and 2 in Fig. 6, it is important to produce sufficiently fast rotational movement of the skateboard around the rear wheels since the upward velocity of the skateboard is produced by this rotational movement. For this purpose, the rider has to kick down on the deck via the rear foot as fast as possible. In addition, it is also important to separate the front foot from the deck during this stage in order not to disturb the rotation movement of the deck.
2. It is important to have Stage 3, that is, both feet should separate from the deck before the tail of the deck hits the ground. If the feet contact the deck and some loads act on the deck during Stage 4, it would significantly disturb the rotational movement of the deck around the tail.
3. It is important for the rear foot to be separated from the deck during Stage 5, in order not to disturb the upward movement of the deck. For the front foot, on the other hand, an appropriate load on the deck is important in order to control the angle of the deck.

4. Conclusions

In the present study, the Ollie jump as a trick in skateboarding was simulated by inputting the motion of feet of a rider. It was found that the simulated Ollie jump was successful since the skateboard reached a sufficient height and became sufficiently horizontal at the peak height. It was also found that the Ollie jump can be divided into five stages from the mechanical point of view. From the parameter study, it was found that large kick angle of the deck or large distance between two trucks of the deck might cause difficulty in the contact of the tail and the ground, while small kick angle or small distance between two trucks might result in excessive rotating angle of the deck. In addition, three important points for a successful Ollie jump were found to be, to produce sufficiently fast rotational movement of the skateboard around the rear wheels, to separate both feet from the deck before the tail of the deck hits the ground, and to separate the rear foot from the deck at the final stage.

References

Adi, E., Aditya, I. and Citrawati, M., Learn street skateboarding through 3D simulations of angle rotations, Journal of Information Technology Education Vol.9 (2010), pp.217-234.

Beach, T. A. C., Parkinson, R. J., Stothart, J. P. and Callaghan, J. P., Effects of prolonged sitting on the passive flexion stiffness of the in vivo lumbar spine, The Spine Journal, Vol.5, No.2 (2005), pp. 145-154.

Determan, J., Frederick, E., Cox, J. and Nevitt, M., Kinetic of the skateboarding kickflip, Proceedings of the Fifth World Congress of Biomechanics (2006), pp.221-224.

Hubbard, M., Lateral dynamics and stability of the skateboard, Journal of Applied Mechanics, Vol.46, No.4 (1979), pp.931-936.

Hubbard, M., Human control of the skateboard, Journal of Biomechanics, Vol.13, No.9 (1980), pp.745-754.

Ispolov, Y. and Smolnikov, B., Skateboard dynamics, Computer Methods in Applied Mechanics and Engineering, Vol.131, (1996), pp.327-333.

Kuleshov, A., Mathematical model of the skateboard, Proceedings of the XXIV International Symposium on Biomechanics in Sports, Salzburg Vol. 2 (2006), pp.715-718.

Kremnev, A. and Kuleshov, A., Dynamics and simulation of the simplest model of a skateboard, Proceedings of the Sixth European Nonlinear Dynamics Conference, Saint Petersburg. (2008), http://www.pages.drexel.edu/~hgk22/courses/MEM355/Skateboard_1.pdf (accessed on 22 March, 2021).

Varszegi, B., Takacs, D., Stepan, G. and Hogan, S., Balancing of the skateboard with reflex delay, Proceedings of the Eighth European Nonlinear Dynamics Conference, Vienna, (2014), http://real.mtak.hu/16334/1/498.pdf (accessed on 22 March, 2021).

Vorlicek, M., Svoboda, Z. and Prochazkova, M., Analysis of muscle activity in various performance levels of ollie jumps in skateboarding: a pilot study, Acta Gymnica Vol.45, No.1 (2015), pp.41-44.

[DOI: 10.1299/mej.21-00230]